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LOADS EXPERIENCED BY THE A4D-2 AIRPLANE
DURING LANDINGS WITH EXTERNAL STORES,
DURING LANDINGS ON AN ARRESTING CABLE
AND DURING UNSYMMETRICAL LANDINGS

November 1962

Prepared under Navy, BuWeps
Contract NOa(s) 59-6226c

Final Report No. LB-31074

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LOADS EXPERIENCED BY THE A4D-2 AIRPLANE DURING LANDINGS WITH EXTERNAL STORES, DURING LANDINGS ON AN ARRESTING CABLE AND DURING UNSYMMETRICAL LANDINGS

NOVEMBER 1962

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Final Report No. LB-31074

Douglas Aircraft Company, Inc.
Long Beach, California

ABSTRACT

Data are presented showing the loads developed during actual landings of the A4D-2 airplane with external stores mounted on the wing, during unsymmetrical landings and during landings in which the gear traversed an arresting cable. Results of a dynamic analysis are compared with the loads experienced during the external store landings only.

The correlation of analysis and theory was not considered satisfactory insofar as the external store accelerations were concerned. Recommendations for improving and extending the analytical work are presented.

The work described in this report represents the second phase of a comprehensive ground loads investigation, the first phase of which is reported in Douglas Aircraft Co. Report LB-31038 dated Oct. 1962.

FOREWORD

The work described in this report was accomplished by Douglas Aircraft Company, Inc., Aircraft Division, Long Beach, California for the Bureau of Naval Weapons, Washington, D. C. under Contract NOa(s) 59-6226c. It represents a summary of the second phase of a comprehensive examination of the loads experienced by Naval Aircraft during landings.

The project was performed under the general direction of Mr. C. T. Newby of the Bureau of Naval Weapons with Mr. D. C. Lindquist acting as cognizant technical project head. It was conducted by Douglas Aircraft Company with Mr. F. C. Allen providing the technical direction and Mr. L. B. Mosby acting as Chief Technical Investigator.

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LIST OF SYMBOLS

$a, \dot{a}, \ddot{a}$	Motion at axle, parallel with strut, of unsprung mass of rolling assembly
$\bar{a}$	Distance from lower piston bearing to axle parallel to strut with strut fully extended
A_o	Gross orifice area without reduction for pin
A_1	Internal area of oleo piston
A_{POD}	Cross-sectional area of piston based on the outside diameter at the lower bearing
A_R	Cross-sectional area of rebound chamber at the piston upper bearing
A_{SPL}	Cross-sectional piston area at the upper bearing including splines
α_1	Pitching rotation of wing in the natural mode shapes
α_1'	Slope of the α_1 curve versus wing station
α_{cg}	Fuel tank pitching acceleration
$\bar{b}$	Distance from upper to lower piston bearing parallel to strut, strut fully extended
β	Torsional motion of unsprung mass about strut centerline
B_{ij}	Coefficients of displacements in airplane equation of motion
$\bar{C}$	Damping coefficient perpendicular to strut
C_β	Damping coefficient of strut in torsion
C_S	Sidewise strut damping coefficient
C_1	Coefficient of force from gear
$\Delta, \dot{\Delta}, \ddot{\Delta}$	Motion at axle, perpendicular to strut, of unsprung mass of rolling assembly
d	Perpendicular distance from centerline of strut to centerline of wheel axle intersection

LIST OF SYMBOLS (Cont'd.)

δ	Distance from axle to gear attach point with strut fully extended
δ_c	Fuel tank longitudinal acceleration, center accelerometer No. 3
δ_{cg}	Fuel tank center of gravity fore-aft acceleration
D_i	Coefficient of moment from gear
$\bar{e}$	Distance from axle to strut centerline normal and forward of strut
E_1	Energy absorbed by first gear to contact ground
E_i	Vector column of constants
ϕ	Angle of strut with vertical; airplane angle of roll
f	Frequency
F_i	Coefficient of moment from gear
F_{HG}	Force on the gear at the ground parallel to the ground
FRL	Fuselage Reference Line
F_{VG}	Force on the gear at the ground normal to the ground
h_a	Fuel tank vertical acceleration, aft accelerometer No. 5
g	Acceleration caused by gravity
h_i	Vertical translation of the wing in the natural mode shapes
h_i'	Slope of the h_i curve versus wing station
h_{cg}	Fuel tank center of gravity vertical acceleration
h_f	Fuel tank vertical acceleration, forward accelerometer No. 2
I_R	Mass moment of inertia of rolling assembly

LIST OF SYMBOLS (Cont'd.)

I_v	Rotational moment of inertia of unsprung weight about strut centerline
K_{32}, K_{33}	$K_{32} + SK_{33}$ is deflection aft due to force acting aft perpendicular to strut
K_4	Strut influence coefficient, side deflection due to unit upward force parallel to strut at wheel-axle intersection
K_x	Lateral radius of gyration of airplane
λ_a	Fuel tank lateral acceleration, aft accelerometer No. 4
λ_{cg}	Fuel tank center of gravity lateral acceleration
λ_f	Fuel tank lateral acceleration, forward accelerometer No. 1
ℓ	Lateral moment arm of gear force about airplane c.g.
M	Generalized mass matrix; airplane mass W/g
MAC	Mean Aerodynamic Chord
$Q, \dot{Q}, \ddot{Q}$	Airplane motion, generalized coordinates
r	Mean contact radius of splines at the upper piston bearing
R_o	Radius of undeflected tire
S_c	Maximum strut stroke
T_{H_1}	Generalized airplane coefficients of force at gear attach point
T_{α_1}	Generalized coefficients of moments at gear attach point
$T_{G\theta}$	Matric row of spanwise wing slope components at the main gear attach point
μ_1	Bearing coefficients of friction before strut moves - static friction
μ_2	Bearing coefficients after strut moves

LIST OF SYMBOLS (Cont'd.)

$\mu_{3,4,5,6}$	Coefficient of friction for lower bearing (3,4) and torque (5,6) odd numbers before strut moves, even numbers after strut moves
μ_s	Ground coefficient of sliding friction
V_E	Air volume in oleo, strut extended
V_L	Forward velocity of airplane
V_v	Vertical velocity of airplane at contact
W	Airplane gross weight
WL	Wing lift
x_{cg}	Fuel tank yawing acceleration
Y_2	Motion of unsprung mass rolling assembly at axle perpendicular and sidewise to strut, relative to ground
Z	Vertical coordinate of ground contact point
Z_o	Initial (starting value) of Z

SUMMARY

This report presents the results of the second phase of a landing loads investigation conducted for the purpose measuring the loads on an A4D-2 airplane during landings and drop tests and for the purpose of determining the accuracy with which these loads may be calculated by means of dynamic analyses.

Phase I of this work compared the loads experienced by a clean airplane during nominally symmetrical landings on smooth runways with the loads obtained in drop tests and with the loads computed by advanced analytical methods. The complete Phase I investigation is reported in References 1 through 4. A detailed description of instrumentation, which is also applicable to the present report, is contained in Reference 1; a description of the flight tests and the results thereof are given in Reference 2; drop tests are described in Reference 3 and a summary of Phase I including the analytical work is presented in Reference 4. The present report contains the following:

1. A comparison of the accelerations experienced by external stores during actual landings with computed accelerations,

2. Data from actual landings during which the airplane ran over an arresting cable, and

3. Data from actual landings in which there was an initial roll angle of substantial magnitude.

The scope of the project did not include efforts to calculate cable impact or unsymmetrical landing loads.

The results of the external store loads investigation showed that even in nominally symmetrical landings, asymmetric gear loads were developed. These loads excited the asymmetric structural vibrational modes and produced store accelerations which the analysis based on symmetry did not reproduce.

Of the three cable impact landings chosen for data reduction, only one showed an increase in maximum vertical gear load attributable to cable impact. It appears obvious from a study of these data that in order for the cable to produce a critical load, the cable pulse must be superimposed on an existing high load. The ratio of maximum load during impact to load before impact was approximately 1.40.

The asymmetric or rolled landing data is primarily of empirical interest. The vertical load on the first gear was always substantially higher than the second gear, the drag loads on the two gear were approximately equal.

It is recommended that additional work be done in an effort to establish better correlation of test data and theory for the external tank loads and that the theory be applied to the computation of cable impact loads and loads obtained in rolled landings.

INTRODUCTION

The data presented in this report was obtained during an investigation carried out under Navy Contract NOa(s) 59-6226c to evaluate the differences between drop tests and actual landings and to determine the extent to which the loads could be computed by analytical methods. Both main gears of a Douglas A4D-2 airplane were instrumented and oscillograph records obtained during a series of landings, after which the gear were mounted on a drop test airplane and a series of drop tests conducted with the same initial conditions as those of the flight tests. The instrumentation, flight testing and drop testing are described in References 1, 2 and 3, respectively. The dynamic analysis and the comparisons between drop test, flight test and theory are reported in Reference 4.

The flight test phase of the program was concluded by recording the landing loads data which are presented in this report. Two external 150 gallon fuel tanks were attached to the wings of the airplane and extra oscillograph channels added to record the fuel tank accelerations while symmetrical landings were made. The fuel tanks were then removed and other landings carried out to obtain data on the load increments caused by running over an arresting cable just after touch-down. Landings were made at various distances in front of an arresting cable which was stretched across the runway. Unsymmetrical loading data were also obtained from landings made with a large initial roll angle.

The theoretical analysis described in Reference 4 was used to analyze the landings with the external tanks. No analysis was required or performed for the cable impact or unsymmetrical landings.

METHOD OF ANALYSIS

The theoretical analysis which is presented herein for Landings 146, 152 and 155 is an extension of the analysis used in Reference 4. The same equations, basic assumptions and Fortran program were used. The airplane is different only by the addition of two 150 gallon wing tanks full of JP-5 fuel. The airplane natural frequencies and mode shapes for this configuration were obtained from the ground vibration data of Reference 5. Tables 1 and 2, and Figure 1 were taken from Reference 5 and were used to calculate the required input data shown in Table 3.

Figure 2 is a sketch of the external fuel tank and shows the location of the accelerometers. The input geometry and acceleration readout instructions for the computing program are listed in Table 4.

The initial conditions for each landing are listed in Table 5 and the input data shown in Table 6. Table 7 is included from Reference 4 to show the rest of the airplane and gear geometry constants required by the program.

The ground loads plotted in this report were obtained in the same manner as were those in Reference 4. The strain gauge and acceleration data plotted in Reference 2 were used as input to a data reducing Fortran program which calculated the ground loads at intervals of .001 seconds.

PRESENTATION OF DATA

COMPARISON OF FLIGHT TEST AND THEORY FOR EXTERNAL STORE LANDINGS

Figures 3 through 8 show the vertical and horizontal ground loads obtained for the six acceptable landings with external tanks for which data is given in Reference 2. Figures 9 through 14 present a comparison of test and analytical loads for three of the landings with external stores. The theoretical curves are based on an assumption of symmetrical landing conditions so that no asymmetric structural modes are included. The test ground loads for both left and right hand gear loads are plotted, but since there were only two accelerometers available on the right hand fuel tank, the acceleration plots show only the five locations on the left hand tank compared with theoretical.

CABLE IMPACT AND ROLLED LANDINGS

The ground loads for the landings on the arresting cable and for the rolled landings are shown in Figures 15 through 21. There was no theoretical analysis done of these landings.

DISCUSSION OF RESULTS

EXTERNAL TANK TESTS

Examination of Figures 10, 12 and 14 shows that the correlation between theory and test for the fuel tank accelerations is not good. Parts of the curves and some of the peaks show fair agreement, but generally speaking, the correlation is considered unsatisfactory. The reasons for this lack of agreement are as follows:

1. The theory assumes a purely symmetrical landing. Consequently, zero roll and yaw angles were used as initial conditions, and asymmetric vibration modes were not included. Examination of the recorded ground loads (Figures 9, 11 and 13) shows that substantial asymmetry is obtained even though the landings were made as symmetrical as possible. Since asymmetric loads were applied to the gear, substantial asymmetric response could be expected from the tanks which the theory could not duplicate.

2. The structural modes of vibration used in the analysis were obtained from ground vibration tests of the airplane with external stores. The highest frequency investigated in these tests was 33 cps. The theory could not be expected to duplicate higher frequencies.

In spite of the limitations inherent in the theory with respect to asymmetric input and response, better agreement on the vertical and drag accelerations could have been obtained had there been sufficient time to expend on the refinement of the analysis. Unfortunately, funding limitations precluded further effort in this direction.

Of considerable interest is the high magnitude of the right hand gear vertical load recorded in Landing 152 (figure 11). The energy represented by the 18.1 fps sinking speed is 76% of that corresponding to the design ultimate sinking speed (20.8 fps). The load recorded was 93% of the design ultimate. Corroborating evidence of a high vertical ground load is found in the corresponding c.g. acceleration, gear side bending and drag load presented by the flight test records in Reference 2. The high load, which occurred when the tire was flat, is attributed to landing area roughness and would be predicted approximately by theory if the effective change in local landing area slope was on the order of 0.5 degrees

CABLE IMPACT LANDINGS

The effect on ground loads of traversing an arresting cable during the landing impact is shown in Figures 15 through 17. It can be seen that serious load pulses are produced only when cable impact occurs at or near the time for maximum load. It is of interest to note that the load ratio (i.e., maximum load during cable impact divided by the load prior to or just after contact) is approximately the same regardless of the load level.

Numerous other landings were made in the flight test program in which the cable was contacted during the landing impact. However these were not reduced because certain channels of the records were missing or defective. Further examination of these records has disclosed that it might be possible to obtain ground loads for one or the other of the gears for several additional landings. It appears that reduction of this data would yield empirical information of considerable value for future designs.

UNSYMMETRICAL LANDING LOADS

The unsymmetrical landings for which data are presented in Figures 18 through 21 were made with an initial roll angle varying from 5.6° to 10.1° (right wing down). Substantial differences in right and left vertical load appear with the right hand gear load being consistently higher than the left. On the other hand, the drag loads appear to be approximately equal, not only with respect to magnitude, but also with respect to the shape of the load vs. time curve.

The energies absorbed by the two gears were computed by integration of the load versus stroke plus tire deflection curve with the following results:

Landing No.	V_v fps	ϕ_o Deg.	$\dot{\phi}_o$* Deg./Sec.	E_1	E_2	E_1+E_2	$\frac{1}{2}MV_v^2$
				Inch-Pounds ÷ 1000			
167	13.8	5.6	1.7R	267	146	413	483
168	11.1	7.3	4.1R	235	68	303	311
170	14.3	10.1	4.8L	305	130	435	502
171	12.8	8.8	2.2R	329	105	434	396

* R = Right Wing Down

L = Left Wing Down

The agreement between the initial and final energies is of approximately the same nature as noted with symmetrical landings in Reference 4, although in the present instances there were probably larger residual motions in roll and yaw which could not be accounted for precisely. The energy associated with the initial roll rate, $\dot{\phi}_o$, was small being equal to less than one percent of the initial translational energy.

CONCLUSIONS AND RECOMMENDATIONS

Based on the comparisons presented between the data from three landings and the corresponding dynamic analysis, the following conclusions are reached with respect to calculating external store accelerations:

1. A theoretical analysis based on the assumptions stated in this report does not produce satisfactory correlation with test data.

2. Although the correlation could be improved with additional effort using the same basic assumptions, the use of asymmetric inputs and asymmetric structural vibration modes is essential to accurate representation of the actual landings.

3. The high frequency load pulses experienced by the tanks cannot be duplicated by the theory using the ground vibration data of Reference 5 which included modes up to 33 cps only.

To improve the correlation, a two-stage investigation is recommended. First, the gas tank accelerations should be computed using as an input the measured landing gear loads and including asymmetric as well as symmetric mode shapes. These calculations should either demonstrate the accuracy of that portion of the analysis from gear loads to structural accelerations or provide information leading to its improvement. Secondly, the analysis should be performed using asymmetric initial conditions to obtain ground loads as well as external store accelerations. The analytical program developed to date has the capability of accomplishing these investigations without further major additions.

Insufficient cable impact data were obtained to derive general conclusions. It was of interest to note, however, that the load ratio created by cable impact for the three conditions examined appeared to be independent of time of impact, load ratio being defined as the maximum load obtained after cable impact divided by the load which would have existed at the same time without cable impact. The data confirm a somewhat self-evident fact that critical gear loads will be developed from cable impact only when cable impact is superimposed on an existing high load.

From the data reduced for four rolled landings in which the right hand gear hit first, it was noted that the right hand gear vertical load was consistently higher than the left and that drag loads were approximately equal. The right hand gear absorbed 1.8 to 3.5 times the energy of the left hand gear.

It is recommended that the analytical calculations be extended to include correlation with the rolled landing data and the cable impact data.

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TABLE 1

GENERALIZED MASS MATRIX, M *(lb-Sec^2-inch per 1/2 Airplane)

Symmetric Modes

MODE NO.	(2)	(3)	(4)	(5)	(6)	(1)	(7)
MODE (CPS)	10.4	12.9	16.7	21.1	28.8	0(BOBBING)	0$^{\neq}$ (PITCHING)
10.4	3.9664	.2422	-.1056	.2282	-.0244	-.4664	133.6
12.9	.2422	1.4528	.1616	-.1507	.0498	.1194	-45.825
16.7	-.1056	.1616	.4812	-.0074	-.0090	-.2206	7.24
21.1	.2282	-.1507	-.0074	.8292	.0328	-.2537	.9731
28.8	-.0244	.0498	-.0090	.0328	.1461	.0644	-17.317
0(BOBBING)	-.4664	.1194	-.2206	-.2537	.0644	18.080	-3.465
0$^{\neq}$ (PITCHING)	133.6	-45.825	7.24	.9731	-17.317	-3.465	142800.

* M is generalized from the Modal amplitudes and local mass data given in Reference 5. The elements have the stated dimensions when the plotted amplitude of each mode is represented by a reference coordinate of one-inch translation.

$\neq$ Pitching is about x = 235; z = 0

TABLE 2

MODEL A4D-2, BuNo 142088

SYMMETRIC MODE, f = 10.4 cps

CONFIGURATION I

Pick-Up Station		Motion	*Deflection
26	Wing	Lateral	.138
26	Wing	Fore and Aft	0
45	Stabilizer	Lateral	-.132
45	Stabilizer	Fore and Aft	-.092
56	Fin	Fore and Aft	.305
57	Fin	Fore and Aft	.092
57	Fin	Vertical	-.333
93	Wing Store Nose	Fore and Aft	.655
	Wing Store c.g.	Vertical	.087
	Wing Store c.g.	Pitch Angle	.01923
	Wing Store c.g.	Lateral	.356
	Wing Store c.g.	Yaw Angle	-.00705
100	℄ Store Nose	Fore and Aft	.018
	℄ Store c.g.	Vertical	-.069
	℄ Store c.g.	Pitch Angle	.00051
	Engine c.g.	Vertical	-.062
	Engine c.g.	Pitch Angle	-.00026
73	Fuselage	Fore and Aft	-.033
	Fuselage Nose	Fore and Aft	--
	Main Gear Hub	Fore and Aft	.237
	Main Gear Hub	Lateral	-.571
	Nose Gear Hub	Fore and Aft	-.039
	Suspension Spring	Vertical	-.080
	Suspension Spring	Fore and Aft	0
	Clevis	Fore and Aft	-.024

*Note: Linear deflections are in inches; angular deflections are in radians.

TABLE 2 (Cont'd.)

MODEL A4D-2, BuNo 142088

SYMMETRIC MODE, f = 12.9 cps

CONFIGURATION I

Pick-Up Station		Motion	*Deflection
26	Wing	Lateral	--
26	Wing	Fore and Aft	.026
45	Stabilizer	Lateral	--
45	Stabilizer	Fore and Aft	0
56	Fin	Fore and Aft	.359
57	Fin	Fore and Aft	.138
57	Fin	Vertical	-.641
93	Wing Store Nose	Fore and Aft	-.0522
	Wing Store c.g.	Vertical	.293
	Wing Store c.g.	Pitch Angle	-.00537
	Wing Store c.g.	Lateral	.072
	Wing Store c.g.	Yaw Angle	-.00046
100	℄ Store Nose	Fore and Aft	.208
	℄ Store c.g.	Vertical	-.002
	℄ Store c.g.	Pitch Angle	.01144
	Engine c.g.	Vertical	-.026
	Engine c.g.	Pitch Angle	.00036
73	Fuselage	Fore and Aft	-.010
	Fuselage Nose	Fore and Aft	--
	Main Gear Hub	Fore and Aft	-.103
	Main Gear Hub	Lateral	-.103
	Nose Gear Hub	Fore and Aft	.120
	Suspension Spring	Vertical	-.069
	Suspension Spring	Fore and Aft	.069
	Clevis	Fore and Aft	-.100

*Note: Linear deflections are in inches; angular deflections are in radians.

TABLE 2 (Cont'd.)

MODEL A4D-2, BuNo 142088

SYMMETRIC MODE, f = 16.7 cps

CONFIGURATION I

Pick-Up Station		Motion	*Deflection
26	Wing	Lateral	--
26	Wing	Fore and Aft	0
45	Stabilizer	Lateral	--
45	Stabilizer	Fore and Aft	0
56	Fin	Fore and Aft	-.133
57	Fin	Fore and Aft	-.075
57	Fin	Vertical	.120
93	Wing Store Nose	Fore and Aft	-.040
	Wing Store c.g.	Vertical	.033
	Wing Store c.g.	Pitch Angle	-.00204
	Wing Store c.g.	Lateral	.019
	Wing Store c.g.	Yaw Angle	-.00007
100	℄ Store Nose	Fore and Aft	0
	℄ Store c.g.	Vertical	-.129
	℄ Store c.g.	Pitch Angle	-.00092
	Engine c.g.	Vertical	-.133
	Engine c.g.	Pitch Angle	.00133
73	Fuselage	Fore and Aft	0
	Fuselage Nose	Fore and Aft	--
	Main Gear Hub	Fore and Aft	-.095
	Main Gear Hub	Lateral	.395
	Nose Gear Hub	Fore and Aft	-.300
	Suspension Spring	Vertical	-.083
	Suspension Spring	Fore and Aft	0
	Clevis	Fore and Aft	.067

*Note: Linear deflections are in inches; angular deflections are in radians.

TABLE 2 (Cont'd.)

MODEL A4D-2, BuNo 142088

SYMMETRIC MODE, f = 21.1 cps

CONFIGURATION I

Pick-Up Station		Motion	*Deflection
26	Wing	Lateral	--
26	Wing	Fore and Aft	0
45	Stabilizer	Lateral	--
45	Stabilizer	Fore and Aft	--
56	Fin	Fore and Aft	.178
57	Fin	Fore and Aft	.065
57	Fin	Vertical	-.043
93	Wing Store Nose	Fore and Aft	.133
	Wing Store c.g.	Vertical	-.353
	Wing Store c.g.	Pitch Angle	-.00079
	Wing Store c.g.	Lateral	-.079
	Wing Store c.g.	Yaw Angle	.00054
100	℄ Store Nose	Fore and Aft	-.029
	℄ Store c.g.	Vertical	.064
	℄ Store c.g.	Pitch Angle	-.00029
	Engine c.g.	Vertical	.126
	Engine c.g.	Pitch Angle	-.00170
73	Fuselage	Fore and Aft	0
	Fuselage Nose	Fore and Aft	--
	Main Gear Hub	Fore and Aft	-.025
	Main Gear Hub	Lateral	-.049
	Nose Gear Hub	Fore and Aft	.059
	Suspension Spring	Vertical	.064
	Suspension Spring	Fore and Aft	0
	Clevis	Fore and Aft	.068

*Note: Linear deflections are in inches; angular deflections are in radians.

TABLE 2 (Cont'd.)

MODEL A4D-2, BuNo 142088

SYMMETRIC MODE, f = 28.8 cps

CONFIGURATION I

Pick-Up Station		Motion	*Deflection
26	Wing	Lateral	--
26	Wing	Fore and Aft	.031
45	Stabilizer	Lateral	--
45	Stabilizer	Fore and Aft	.101
56	Fin	Fore and Aft	.063
57	Fin	Fore and Aft	.049
57	Fin	Vertical	-.236
93	Wing Store Nose	Fore and Aft	-.018
	Wing Store c.g.	Vertical	-.018
	Wing Store c.g.	Pitch Angle	.00027
	Wing Store c.g.	Lateral	.001
	Wing Store c.g.	Yaw Angle	.00008
100	℄ Store Nose	Fore and Aft	-.012
	℄ Store c.g.	Vertical	.037
	℄ Store c.g.	Pitch Angle	.00073
	Engine c.g.	Vertical	.050
	Engine c.g.	Pitch Angle	-.00025
73	Fuselage	Fore and Aft	.025
	Fuselage Nose	Fore and Aft	---
	Main Gear Hub	Fore and Aft	.012
	Main Gear Hub	Lateral	-.010
	Nose Gear Hub	Fore and Aft	.012
	Suspension Spring	Vertical	-.013
	Suspension Spring	Fore and Aft	-.003
	Clevis	Fore and Aft	0

*Note: Linear deflections are in inches; angular deflections are in radians.

TABLE 3

FLEXIBLE WING DATA

Deflection of the Gear Attach Point

Mode	Mode f cps	M $\frac{Lb\text{-}Sec^2\text{-}In}{Mode}$	h (at Sta. 40)	α	h' (at Sta. 40)	α'
1	0	18.08	1.0	-	-	-
2	10.4	3.9664	-.06	.0014	.0022	.00006
3	12.9	1.4528	.05	-.0004	.0059	0
4	16.7	.4812	-.045	.0008	.0018	.000038
5	21.1	.8292	-.085	.0028	-.0033	.000141
6	28.8	.1461	-.01	-.0009	0	-.000018
7	0	142800.	25.125	1.0	-	-

Mode	m_i	T_{H_i}	T_{α_i}	$T_{G\theta_i}$
1	1.5066	.08333	0	0
2	.3305	-.00027	.0014	.00371
3	.1210	.00282	-.0004	.00616
4	.0401	-.00105	.0008	.00282
5	.0691	.00237	.0028	.00058
6	.0121	-.00387	-.0009	-.00014
7	11900.	2.09375	1.0	0

Mode	B_{ij}	C_i	D_i	F_i
1	0	.05531	0	0
2	-4270	-.000832	.004236	.01122
3	-6570	.02327	-.003304	.05088
4	-11010	-.02618	.01995	.0732
5	-17576	.03425	.04052	.008393
6	-32745	-.3183	-.07392	-.0115
7	0	.000176	.000084	0

See Page 19 for symbols and equations pertaining to this table.

TABLE 3 (Cont'd.)

INPUT DATA

FORMULAS FOR FLEXIBLE WING

$m_i = M_i/12$

$T_{H_i} = (h_i + 40.443\ \alpha_i)/12$

$T_{\alpha i} = \alpha_i$

$T_{G\theta_i} = h_i' + 40.443\ \alpha_i' - .65455\ \alpha_i$

h_i' is the slope of the h_i curve at the gear attach point (Sta. 40)

α_i' is the slope of the α_i curve at the gear attach point

$B_{ij} = -(2\pi f_i)^2$

$C_i = T_{H_i}/m_i$

$D_i = T_{\alpha_i}/m_i$

$F_i = T_{G\theta_i}/m_i$

E_i is calculated by the program

TABLE 4

ACCELERATION READOUTS

Accelerometer Location from Tank Center of Gravity

Readout Row	Accel. No.	Distance from Tank C.G. Long.	Vert.	Lateral	Deflection Equation
2	1	42.1	0	9	$\lambda_f = \lambda_{cg} - 42.1\, x_{cg}$
3	2	42.1	-9	0	$h_f = h_{cg} + 42.1 \alpha_{cg}$
4	3	3.6	0	10.5	$\delta_c = \delta_{cg} + 10.5\, x_{cg}$
5	4	-42.2	0	9	$\lambda_a = \lambda_{cg} + 42.2\, x_{cg}$
6	5	-42.2	-9	0	$h_a = -h_{cg} - 42.2 \alpha_{cg}$

Note: C.G. subscripted quantities are the same as those of pages 13 to 17 except for the change of sign convention for vertical deflection.

Coefficients for Tank Acceleration

Mode	1	2	3	4	5	6	7
Deflection							
h_{cg}	-1	-.087	-.293	-.033	.353	.018	-4.2
δ_{cg}	0	.655	-.052	-.04	.133	-.018	53.7
λ_{cg}	0	.356	.072	.019	-.079	.001	0
α_{cg}	0	.01923	-.00537	-.00204	-.00079	.00027	1
x_{cg}	0	-.00705	-.00046	-.00007	.00054	.00008	0
λ_f	0	.653	.091	.022	-.102	-.002	0
h_f	-1	.723	-.519	-.119	.32	.029	37.9
δ_c	0	.581	-.057	-.041	.139	-.017	53.7
λ_a	0	.058	.053	.016	-.056	.004	0
h_a	-1	-.899	-.066	.053	.386	.007	-46.4

TABLE 5

INITIAL CONDITIONS

LANDINGS WITH EXTERNAL STORES

Landing No.	Gross Weight Lbs.	FRL Angle Degrees	Horiz. C.G. Position % MAC	Wing Lift ÷ Weight	Sink Speed fps	Horiz. Speed Knots
146	13,955	10.6	24.2	1.09	11.0	133.3
150	14,135	8.5	23.3	1.04	13.6	133.7
151	13,895	9.5	24.4	1.07	11.7	134.3
152	14,985	8.0	23.1	1.09	18.1	136.3
153	14,415	9.2	22.3	1.06	14.3	134.4
155	14,195	8.6	23.1	1.10	16.0	133.4

TABLE 5 (Cont'd.)

INITIAL CONDITIONS

UNSYMMETRICAL AND CABLE LANDINGS

Landing No.	Gross Weight lbs.	FRL Angle Degrees	Horiz. C.G. Position % MAC	Wing Lift ÷ Weight	Sink Speed fps	Horiz. Speed Knots
167	13,675	13.0	24.2	1.14	13.8	123.7
168	13,535	13.2	24.0	1.08	11.1	124.0
170	13,195	12.4	23.3	1.07	14.3	130.5
171	12,985	9.5	23.0	1.01	12.8	128.7
179	13,775	11.4	24.4	1.05	18.0	128.0
188	13,285	10.0	23.6	1.06	15.0	126.0
190	12,785	11.3	22.6	1.12	16.0	129.0

TABLE 6

START TIME INPUT DATA

Landing No.	$\dot{Q}_1$	$\ddot{Q}_1$	ϕ	$\dot{a}$	$\ddot{a}$	Δ	$\dot{\Delta}$
146	132.0	-34.74	4.6	131.6	-34.6	.0024	10.6
152	217.2	-34.74	2.0	217.1	-34.7	.001	7.58
155	192.0	-38.6	2.6	191.8	-38.6	.0014	8.71

Landing No.	$\ddot{\Delta}$	Y_2	β	V_L	Z_o	C_1	μ_s
146	-2.79	.0079	.00011	2703.6	-12.00008	.05529	.394
152	-1.21	.0079	.00005	2763.6	-12.00004	.05149	.30
155	-1.75	.0079	.00006	2706.0	-12.00006	.05436	.38

See Page 24 for symbols and equations pertaining to this table.

TABLE 6 (Cont'd.)

FORMULAS FOR START-TIME INPUTS

$\dot{Q}_1$	=	Sink Speed	(in./sec.)
$\ddot{Q}_1$	=	$(1.0 - WL)\ 386$	(in./sec.^{2})
$\dot{a}$	=	$\dot{Q}_1 \cos \phi$	(in./sec.)
$\ddot{a}$	=	$\ddot{Q}_1 \cos \phi$	(in./sec.^{2})
Δ	=	$\left(\frac{1}{K_{32}} W_U\right) (WL) \sin \phi$	(in.)
$\dot{\Delta}$	=	$\dot{Q}_1 \sin \phi$	(in./sec.)
$\ddot{\Delta}$	=	$\ddot{Q}_1 \sin \phi$	(in./sec.^{2})
Y_2	=	$K_4 (W_U)(WL) \cos \phi$	(in.)
β	=	$(W_U)(WL) \frac{d}{K_\beta} \sin \phi$	(rad./sec.)
Z_o	=	$-(12 + (\Delta) \sin \phi)$	(in.)
C_1	=	T_{H_1}/m_1	(1/lb.sec.^{2})
μ_s	=	Average Ground Coefficient of Friction at Time of Spin-up, from Flight Test Data	
ϕ	=	Pitch Attitude -6°	

TABLE 7

INPUT CONSTANTS FROM GEAR GEOMETRY

$\bar{a}$	$= 20.2$ in.	r	$= 2.0615$ in.
A_o	$= .5391$ in.^{2}	R_o	$= 12.0$ in.
A_1	$= 8.71$ in.^{2}	S_c	$= 16.0$ in.
A_{POD}	$= 11.04$ in.^{2}	V_E	$= 173.5$ in.^{3}
A_R	$= 2.36$ in.^{2}	W_U	$= 149$ lbs.
A_{SPL}	$= 13.4$ in.^{2}	$\mu_{1,3,5}$	$= .65$
$\bar{b}$	$= 9.7$ in.	$\mu_{2,4}$	$= .20$
δ	$= 53.435$ in.	μ_6	$= .25$
$\bar{e}$	$= 0$	$\bar{C}$	$= 20.82$ lb.-sec./in.
d	$= 6.75$ in.	C_S	$= 26.0$ lb.-sec./in.
I_R	$= 11.25$ lb.-in.-sec.^{2}	C_β	$= 1000$ in.-lb.-sec./Rad.
I_V	$= 20.0$ lb.-in.-sec.^{2}		

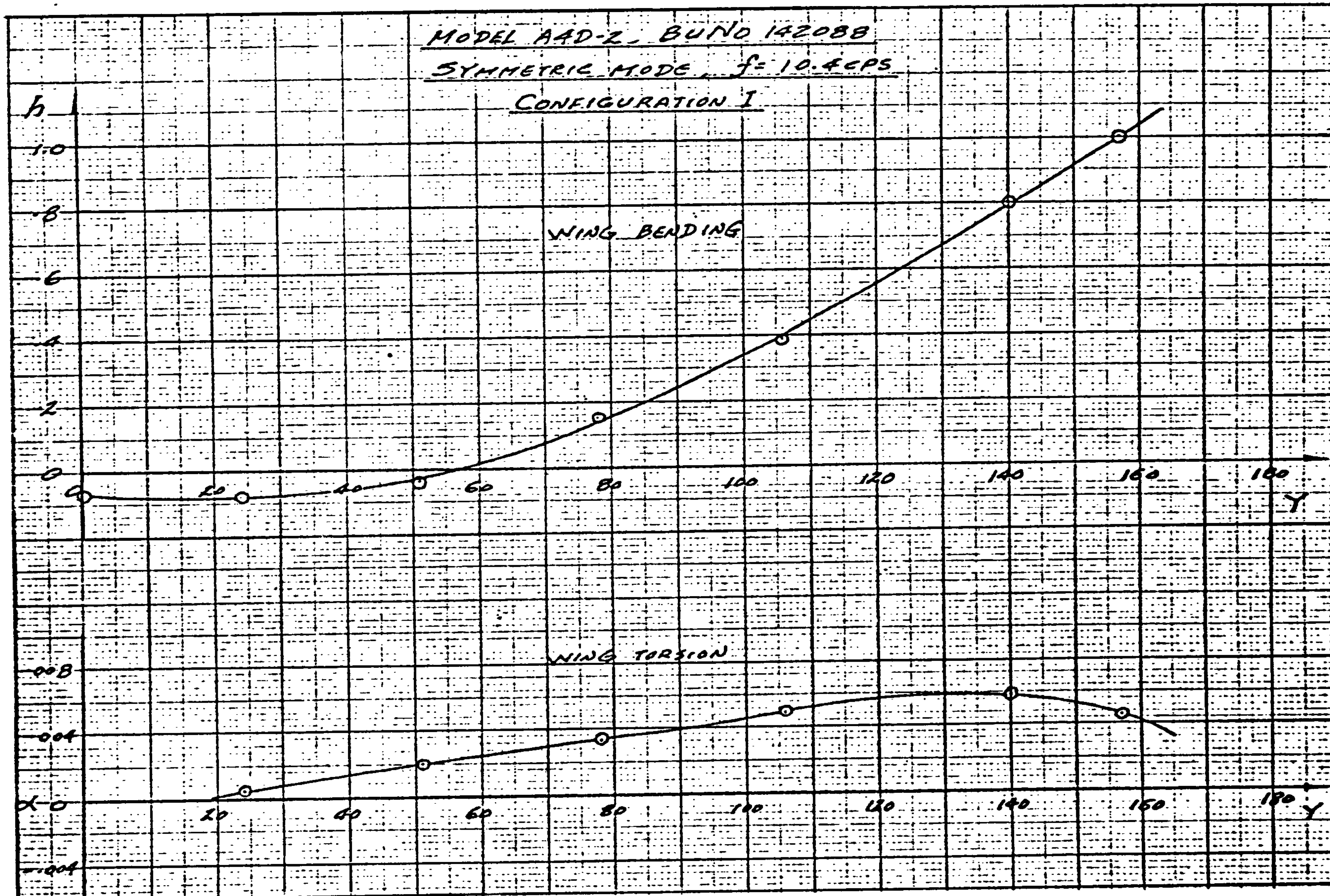


Figure 1. Vertical Deflection, h, and Pitching Rotation, α, for the A4D-2 Symmetric Mode with External Tanks Attached.

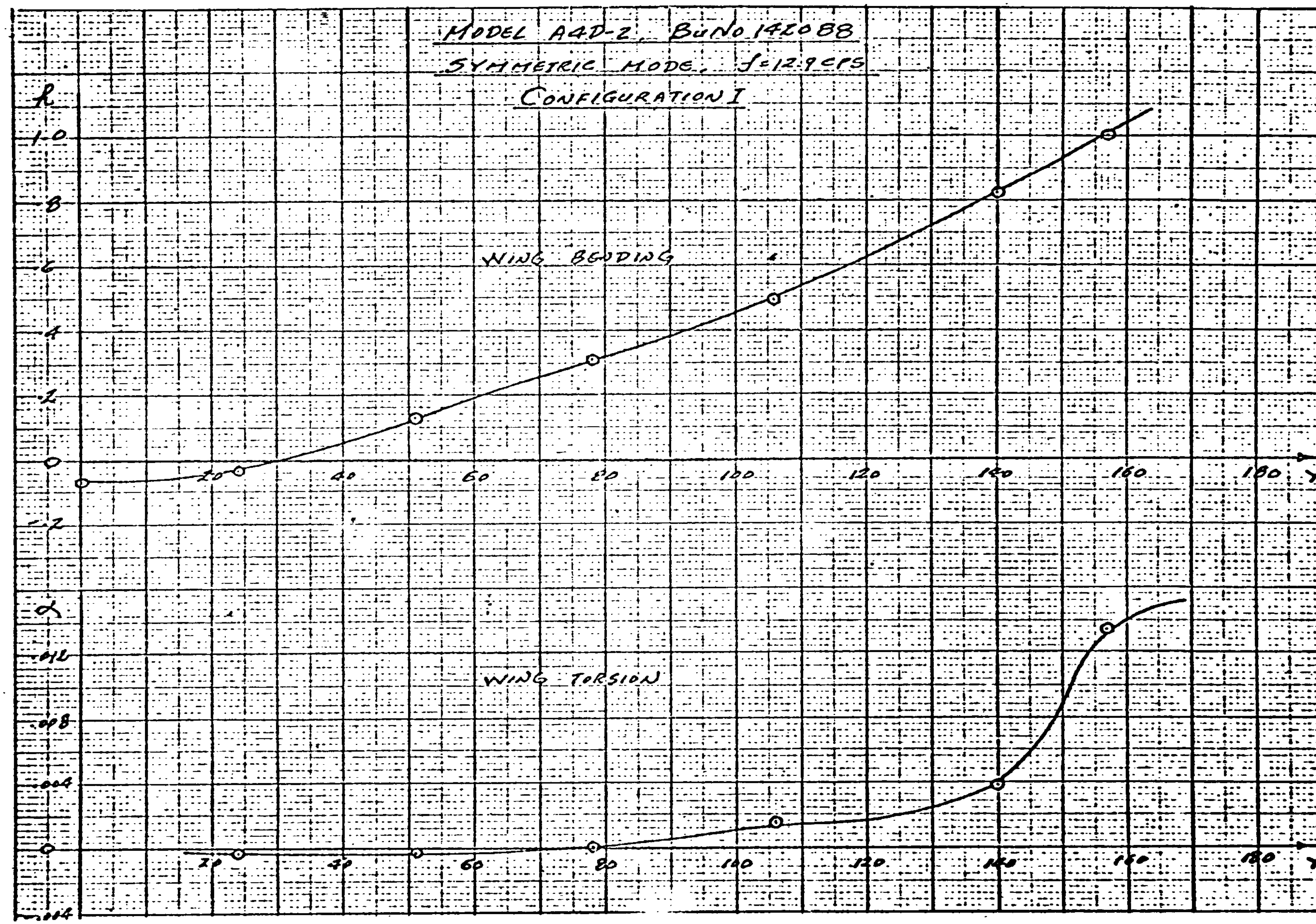


Figure 1. Continued

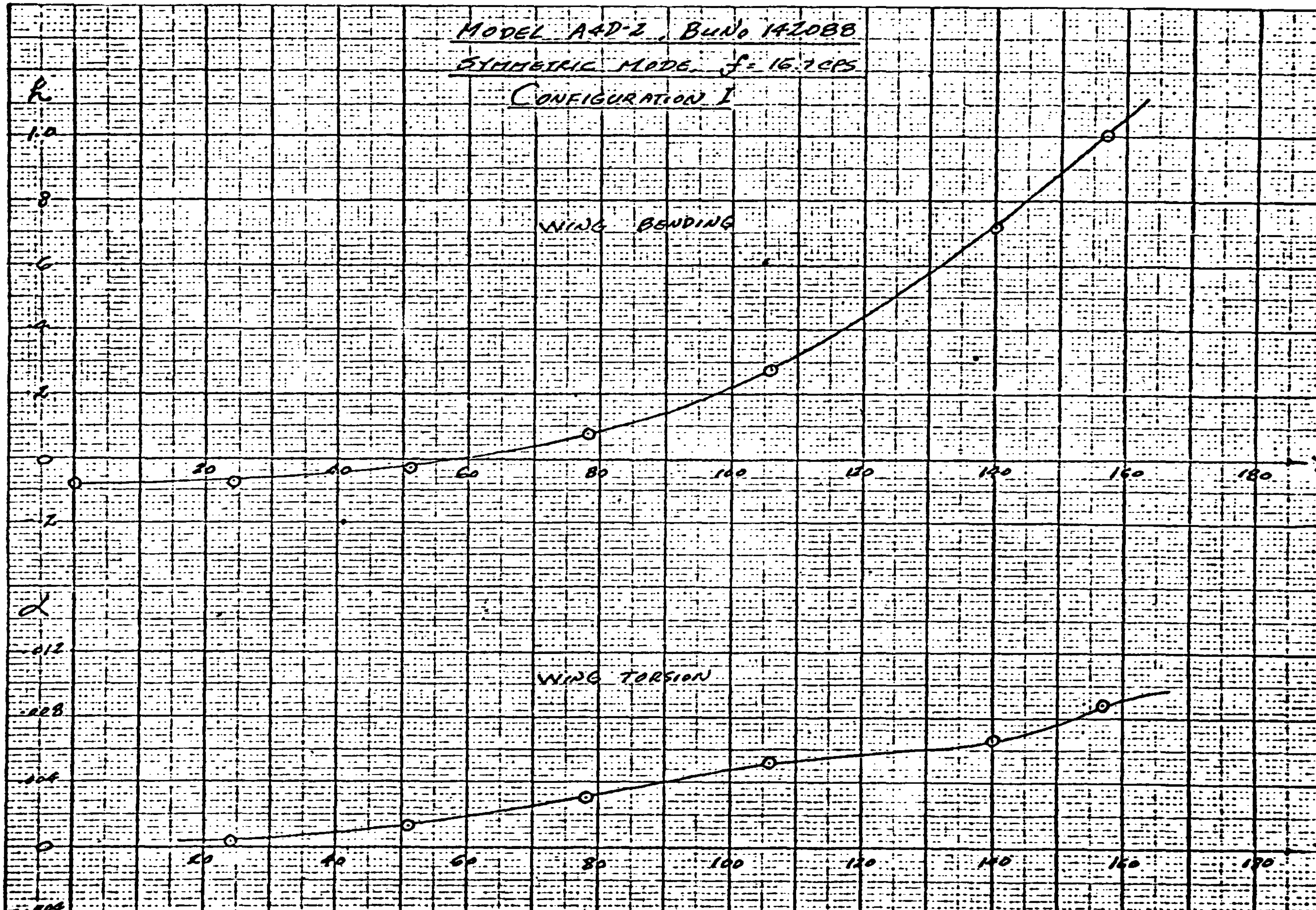


Figure 1. Continued

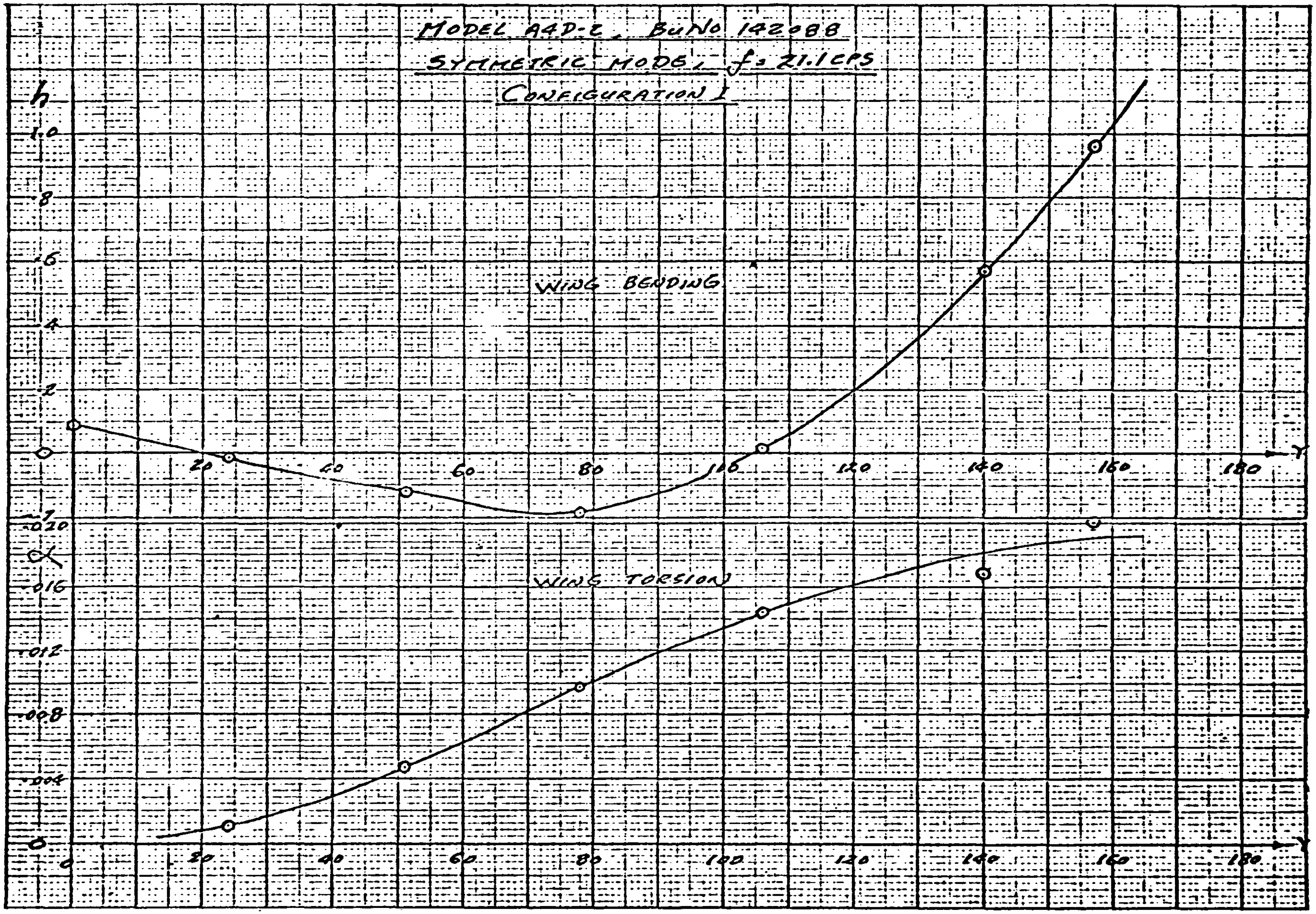


Figure 1. Continued

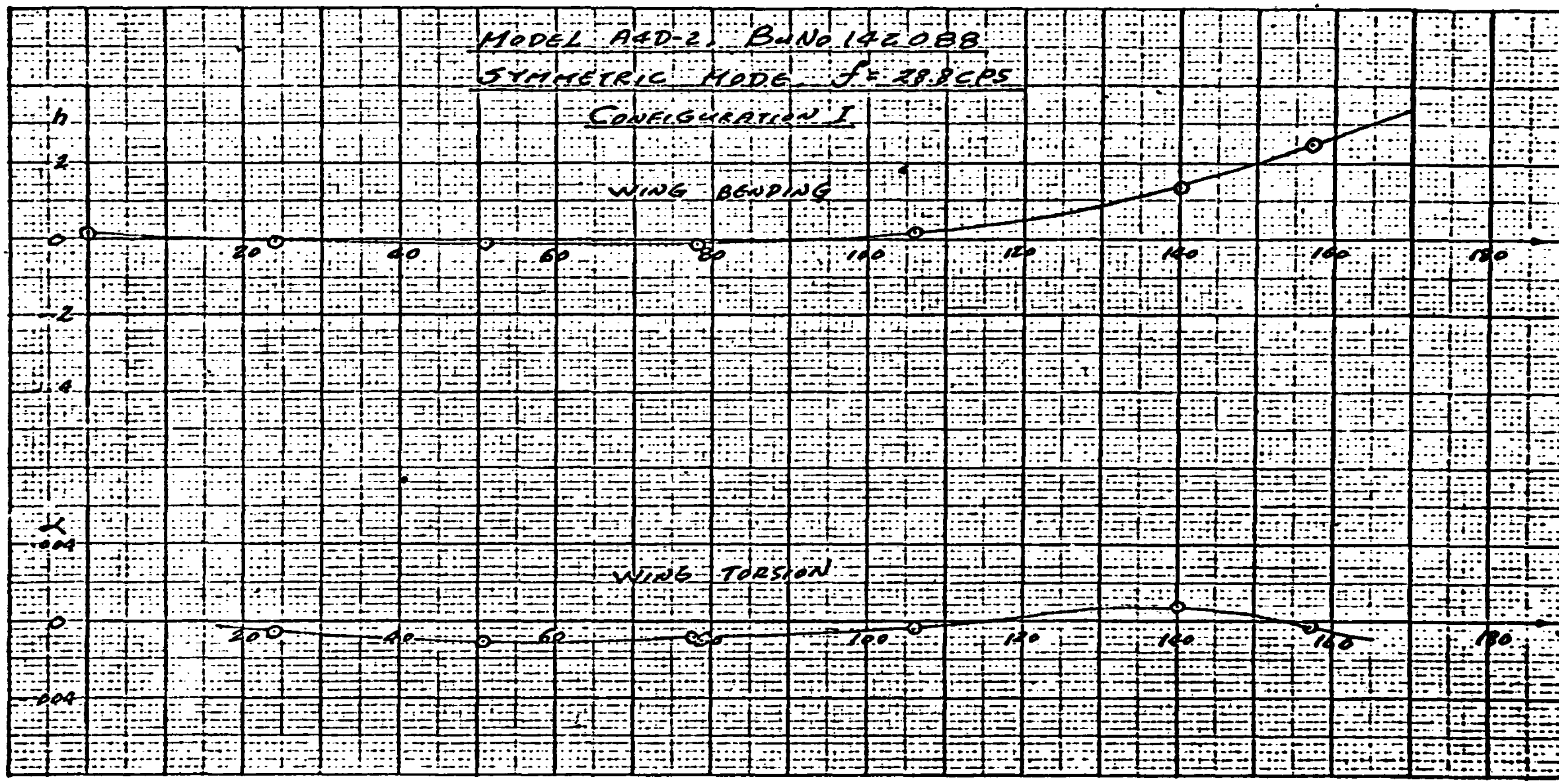


Figure 1. Continued

AERO 1 C

150 GALLON EXTERNAL FUEL TANK

DWG 5548328

SIDE VIEW

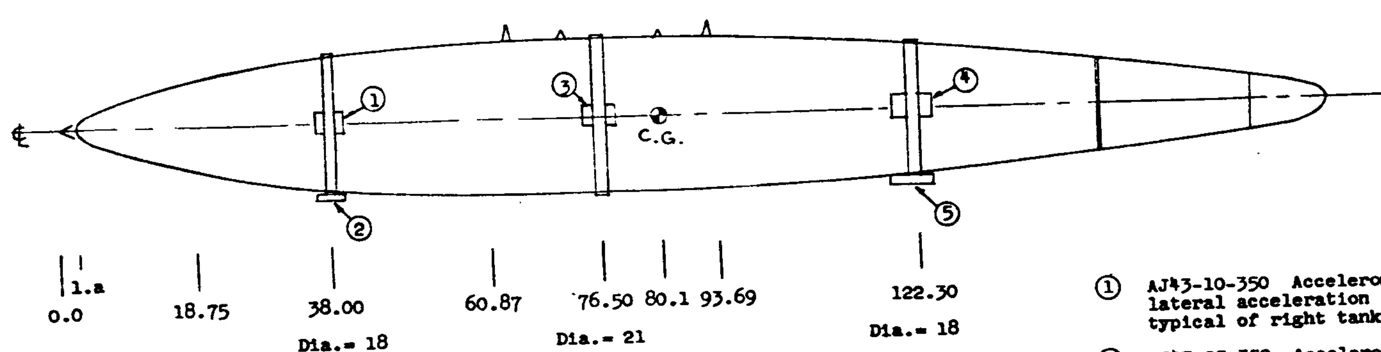
ACCELEROMETER

INSTALLATION

FOR

LANDING LOADS PROGRAM

NOTE: Accelerometers aligned perpendicular and parallel to Fuselage Reference Line



1. AJ43-10-350 Accelerometer - Left tank lateral acceleration - Mounted outb'd, typical of right tank
2. AJ43-25-350 Accelerometer - Left tank normal acceleration, typical of right tank
3. AJ43-10-350 Accelerometer - Left tank longitudinal acceleration - Mounted outbr'd
4. F-10-350 Accelerometer - Left tank lateral acceleration - Mounted outb'rd
5. AJ43-25-350 Accelerometer - Left tank, normal acceleration

Positive Accelerations: Up, Outboard, Forward

Figure 2. Schematic of External Fuel Tank Showing Accelerometer Locations.

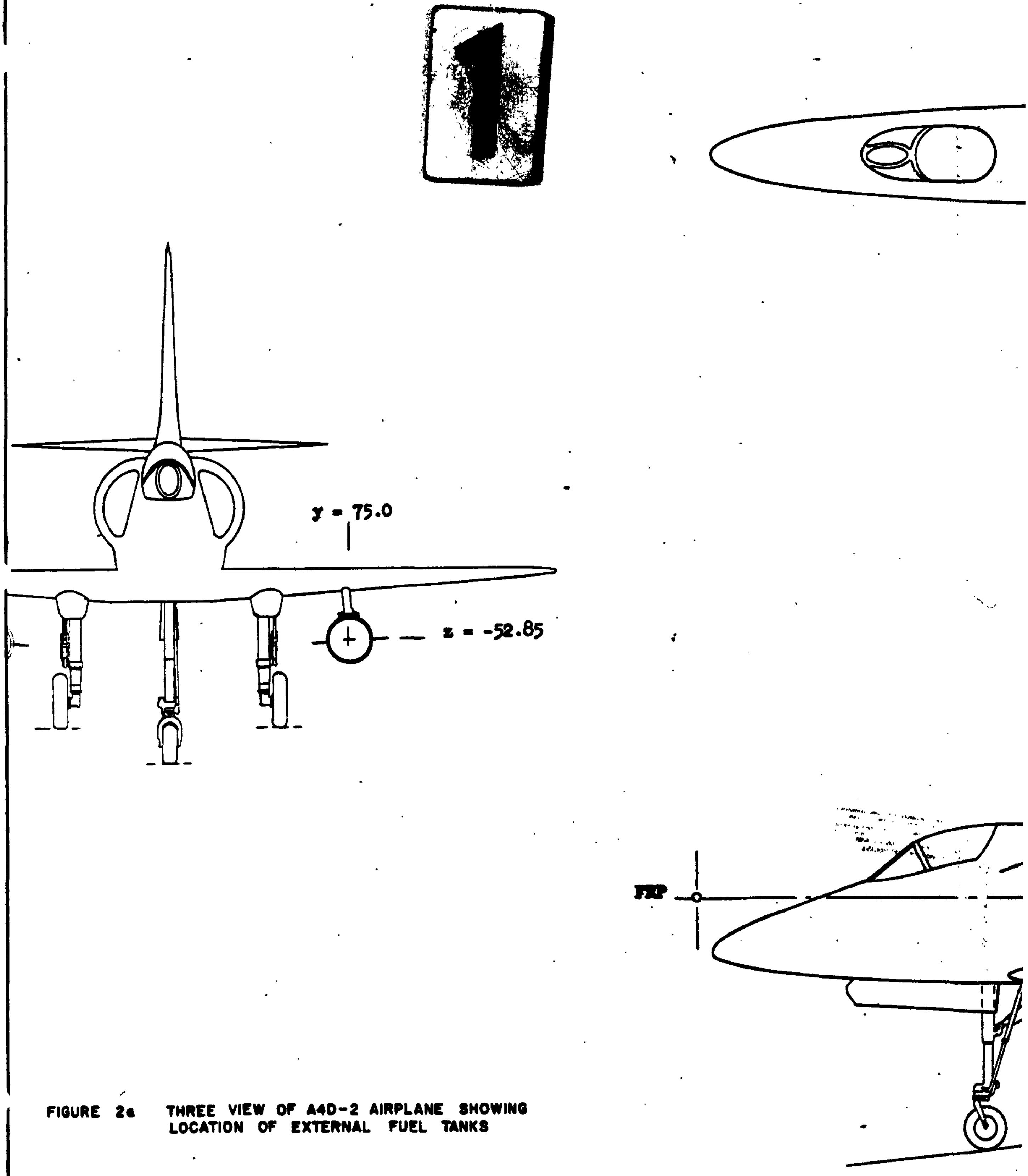
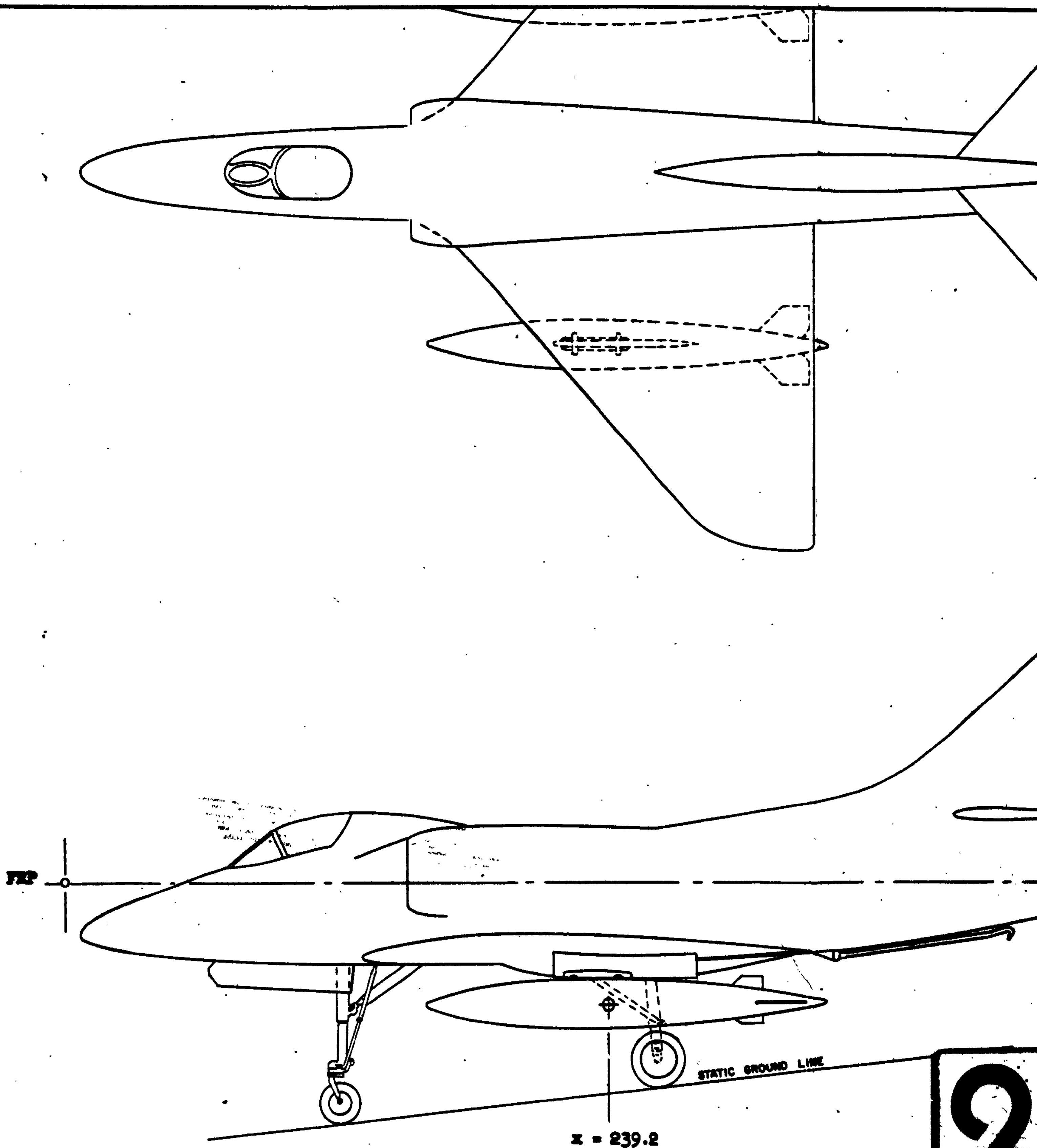
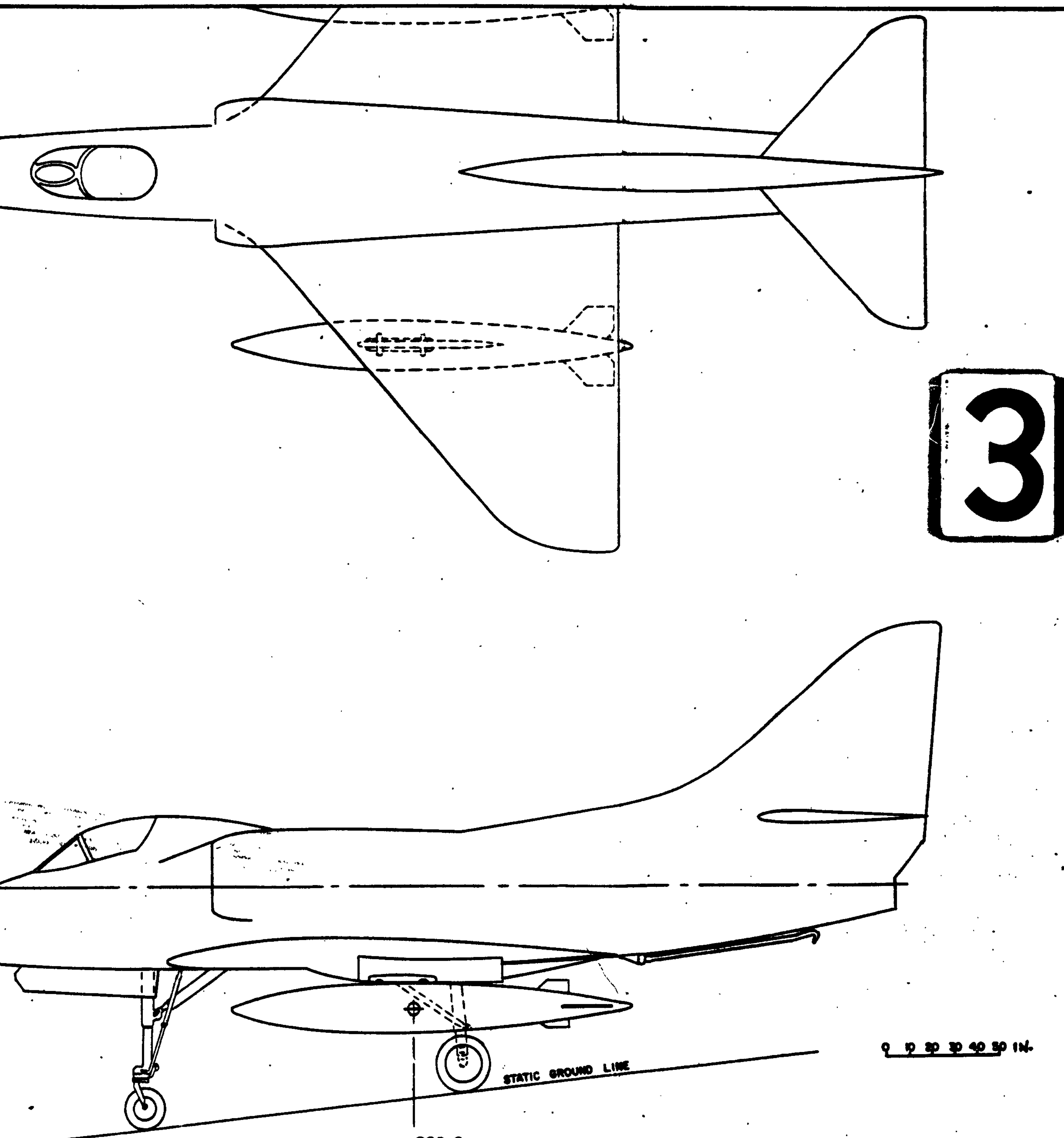


FIGURE 2a THREE VIEW OF A4D-2 AIRPLANE SHOWING LOCATION OF EXTERNAL FUEL TANKS



2



3

GROUND LOADS

LANDINGS WITH EXTERNAL TANKS

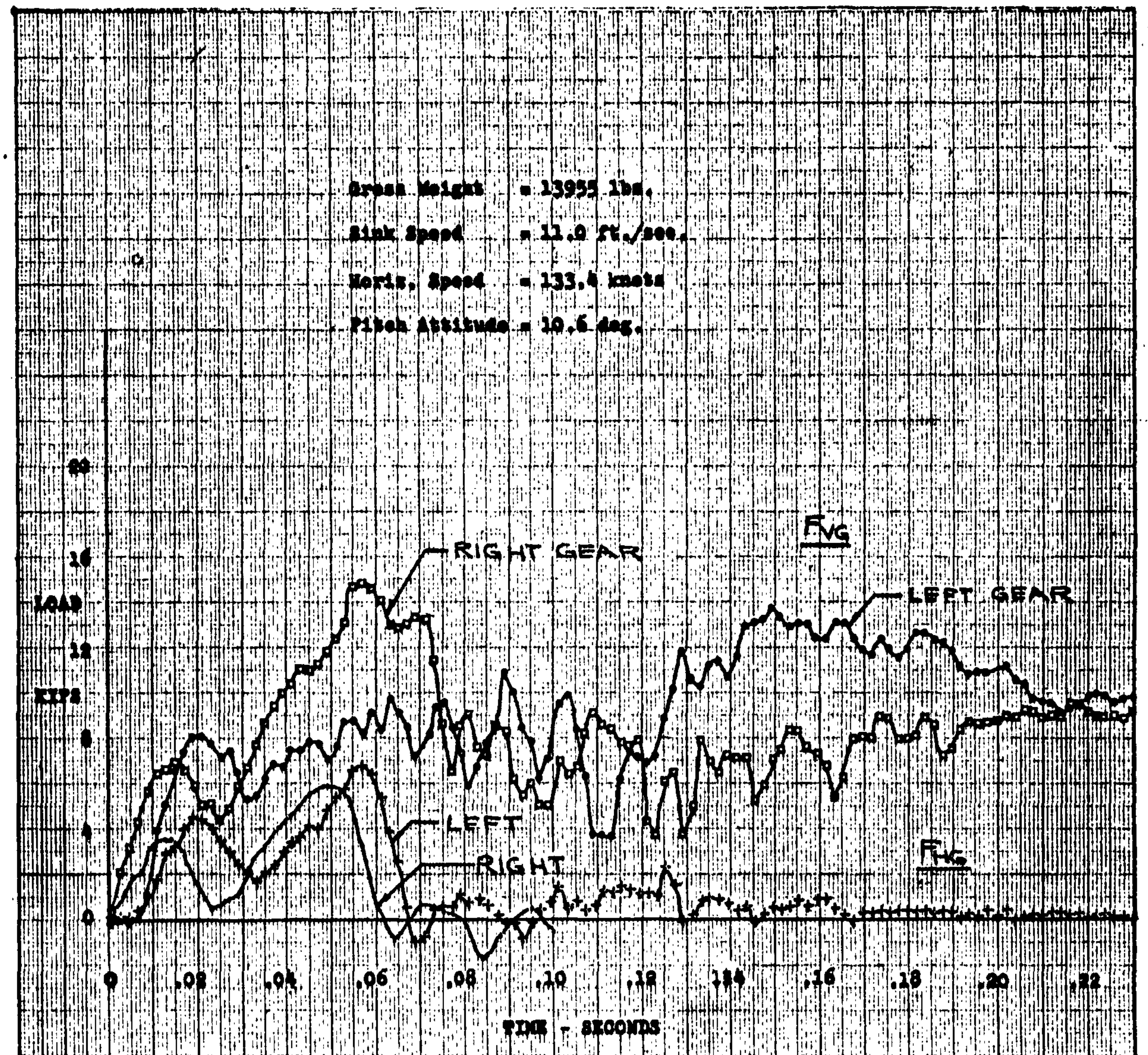


Figure 3. Vertical and Horizontal Ground Loads

Landing 146 with External Fuel Tanks

GROUND LOADS

LANDINGS WITH EXTERNAL TANKS

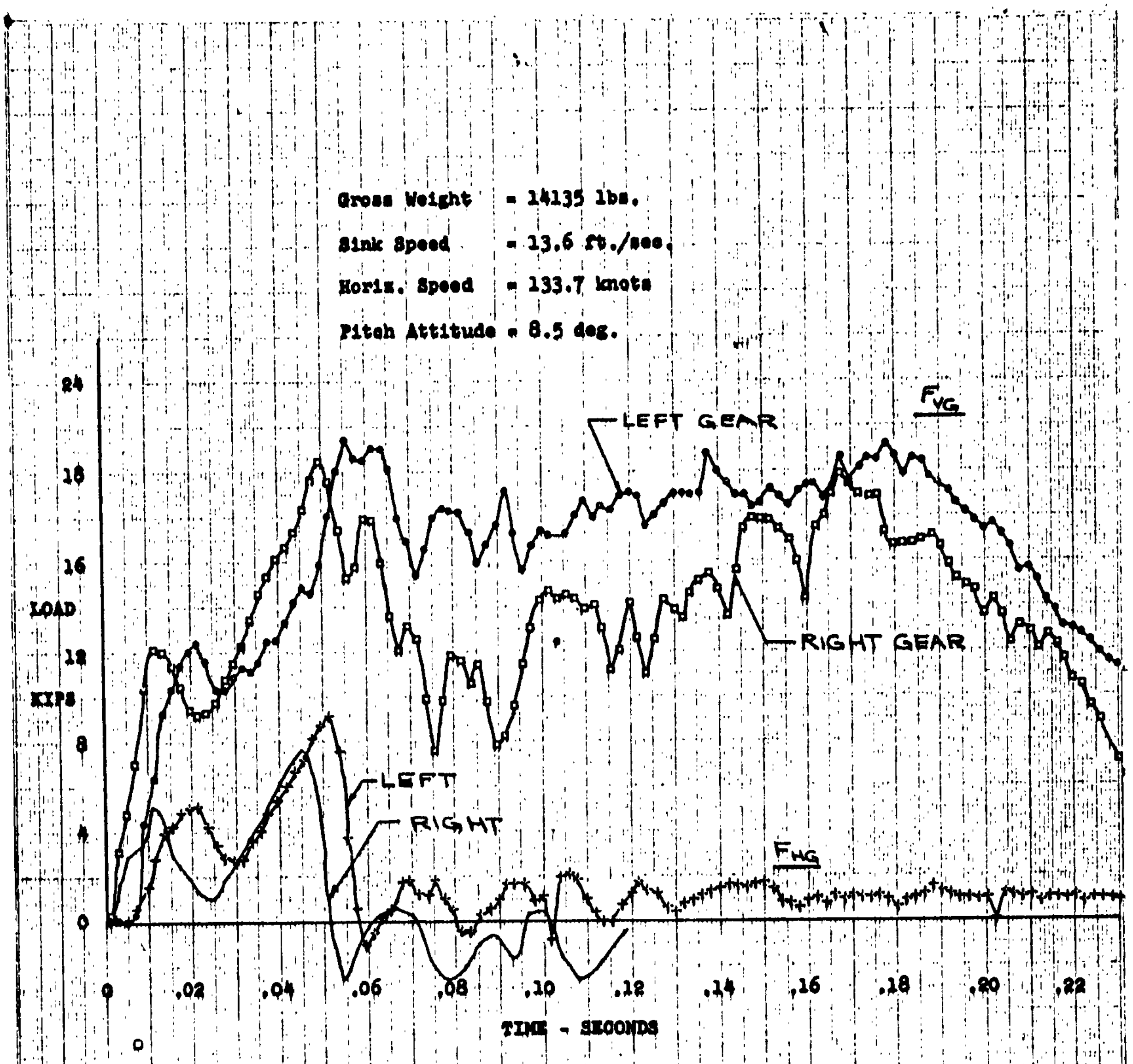


Figure 4. Vertical and Horizontal Ground Loads
Landing 150 with External Fuel Tanks

GROUND LOADS

LANDINGS WITH EXTERNAL TANKS

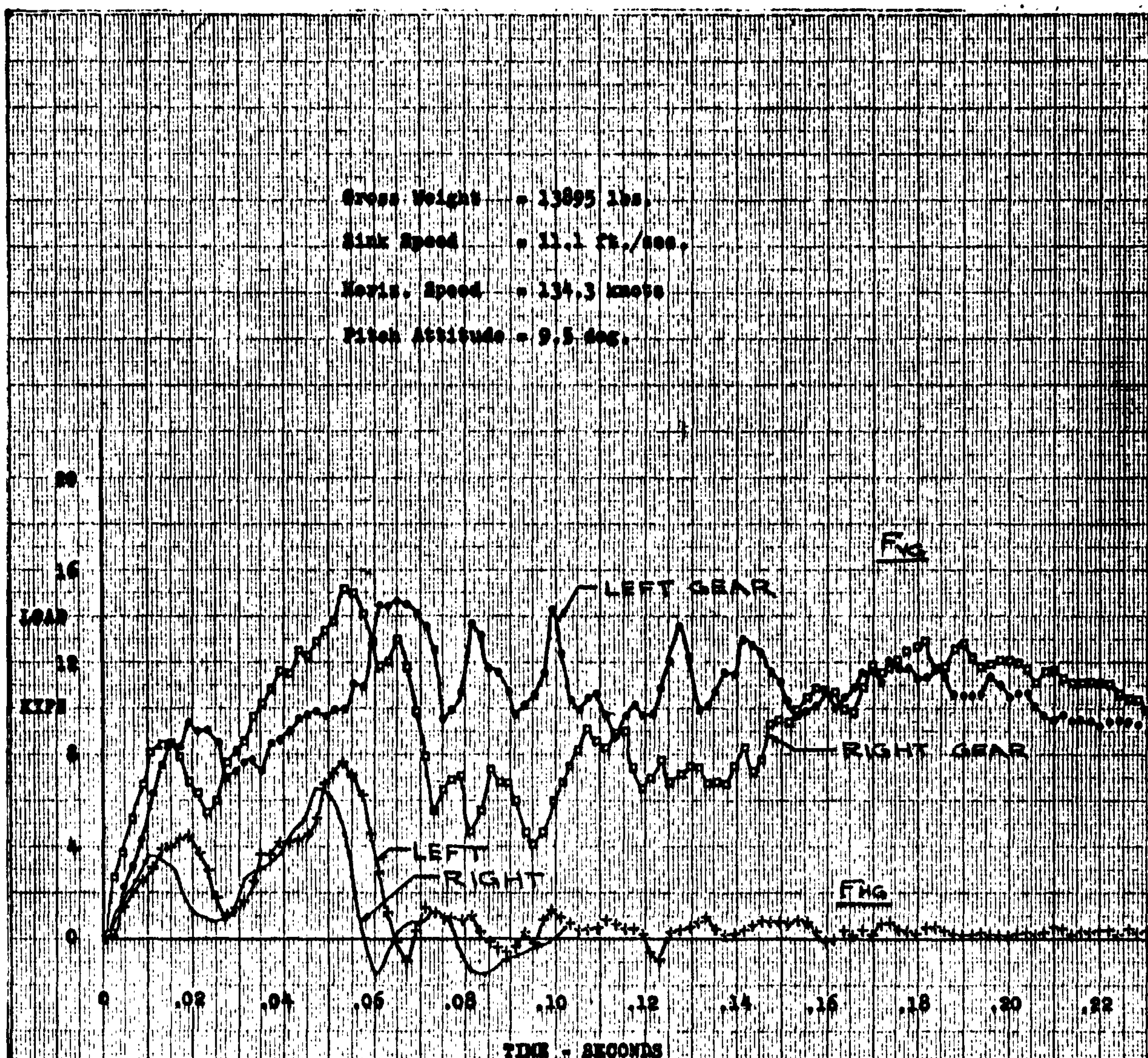


Figure 5. Vertical and Horizontal Ground Loads
Landing 151 with External Fuel Tanks

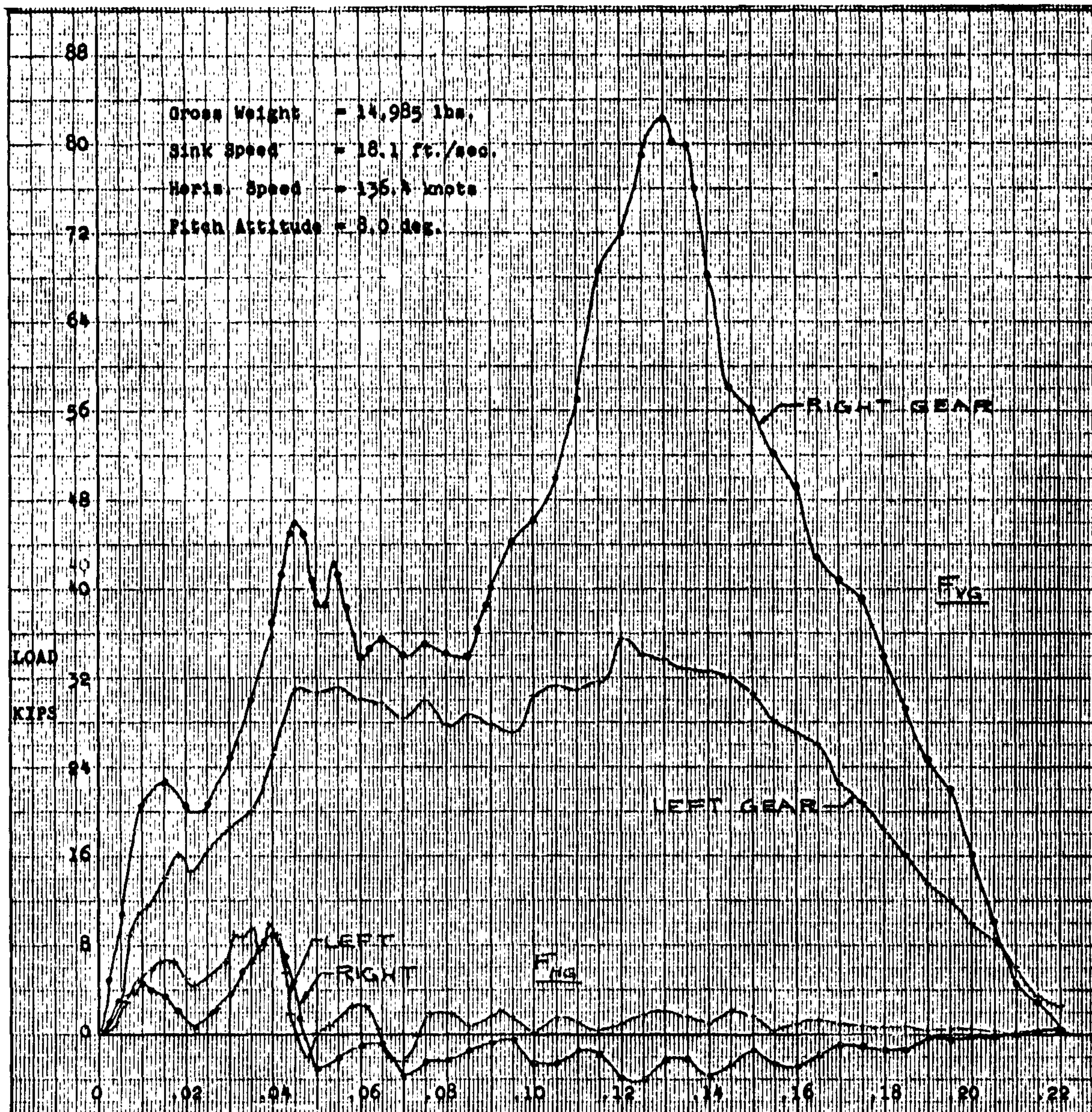


Figure 6. Vertical and Horizontal Ground Loads
Landing 152 with External Fuel Tanks

GROUND LOADS

LANDINGS WITH EXTERNAL TANKS

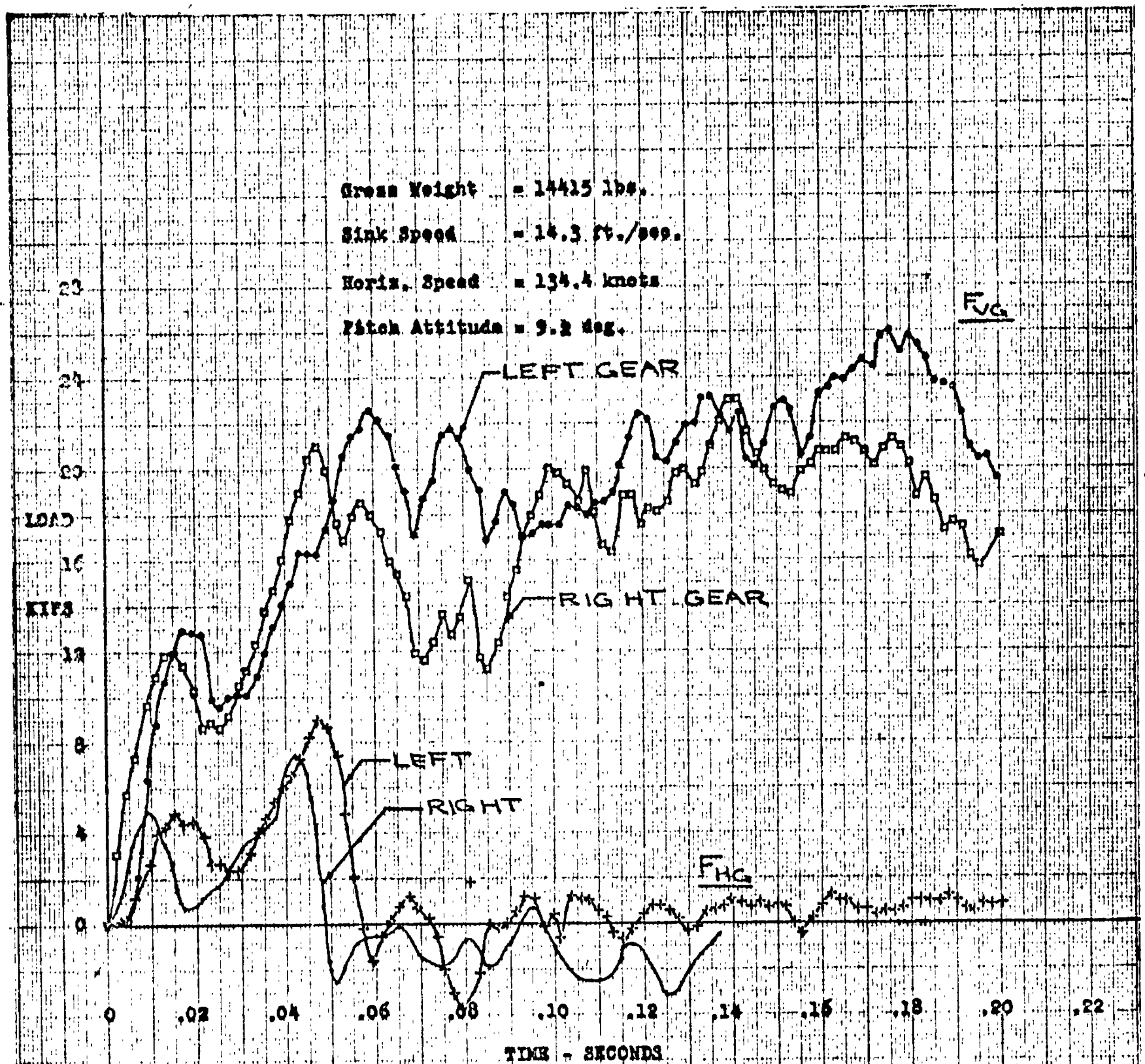


Figure 7. Vertical and Horizontal Ground Loads Landing 153 with External Fuel Tanks

GROUND LOADS

LANDINGS WITH EXTERNAL TANKS

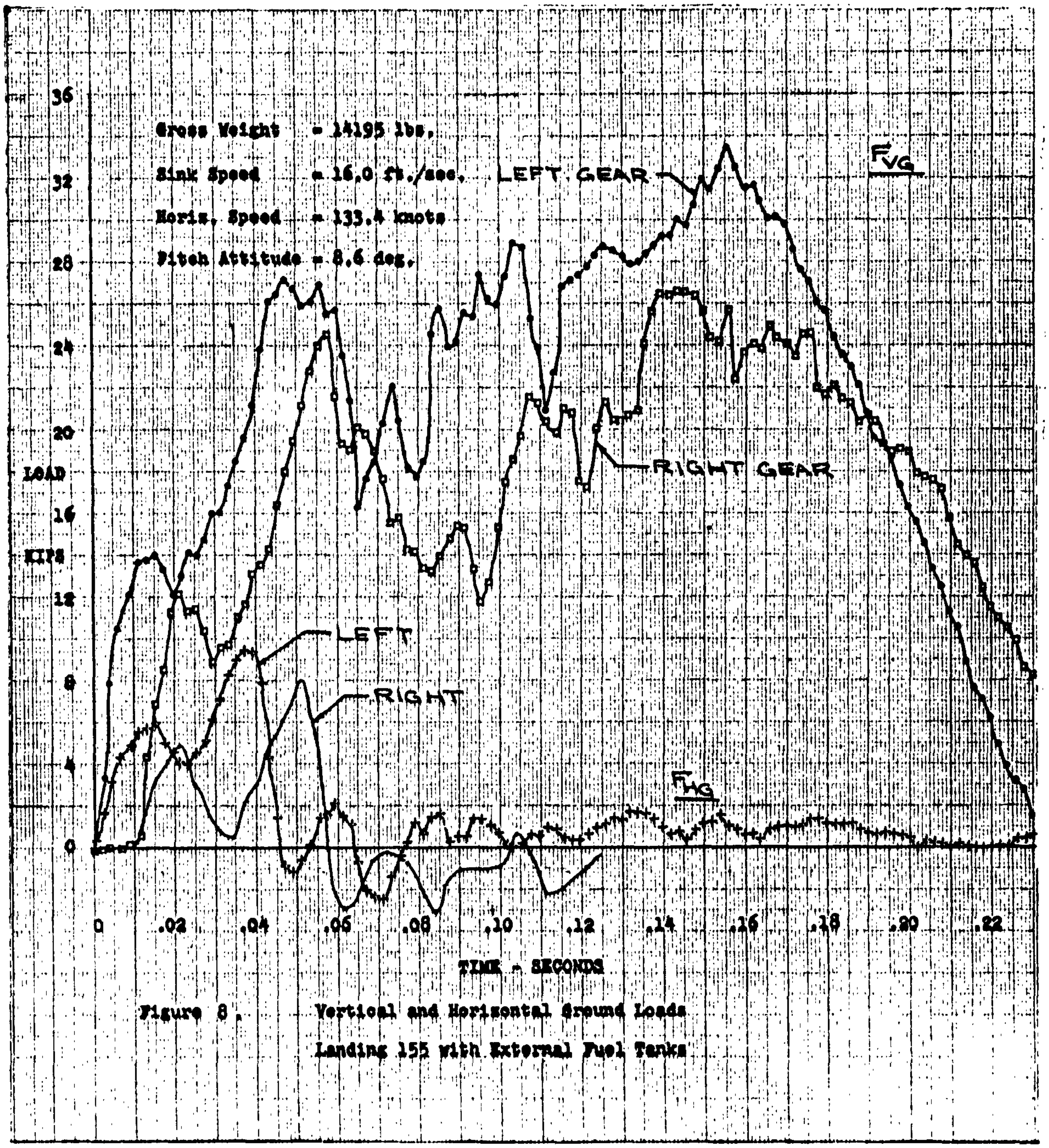


Figure 8. Vertical and Horizontal Ground Loads
Landing 155 with External Fuel Tanks

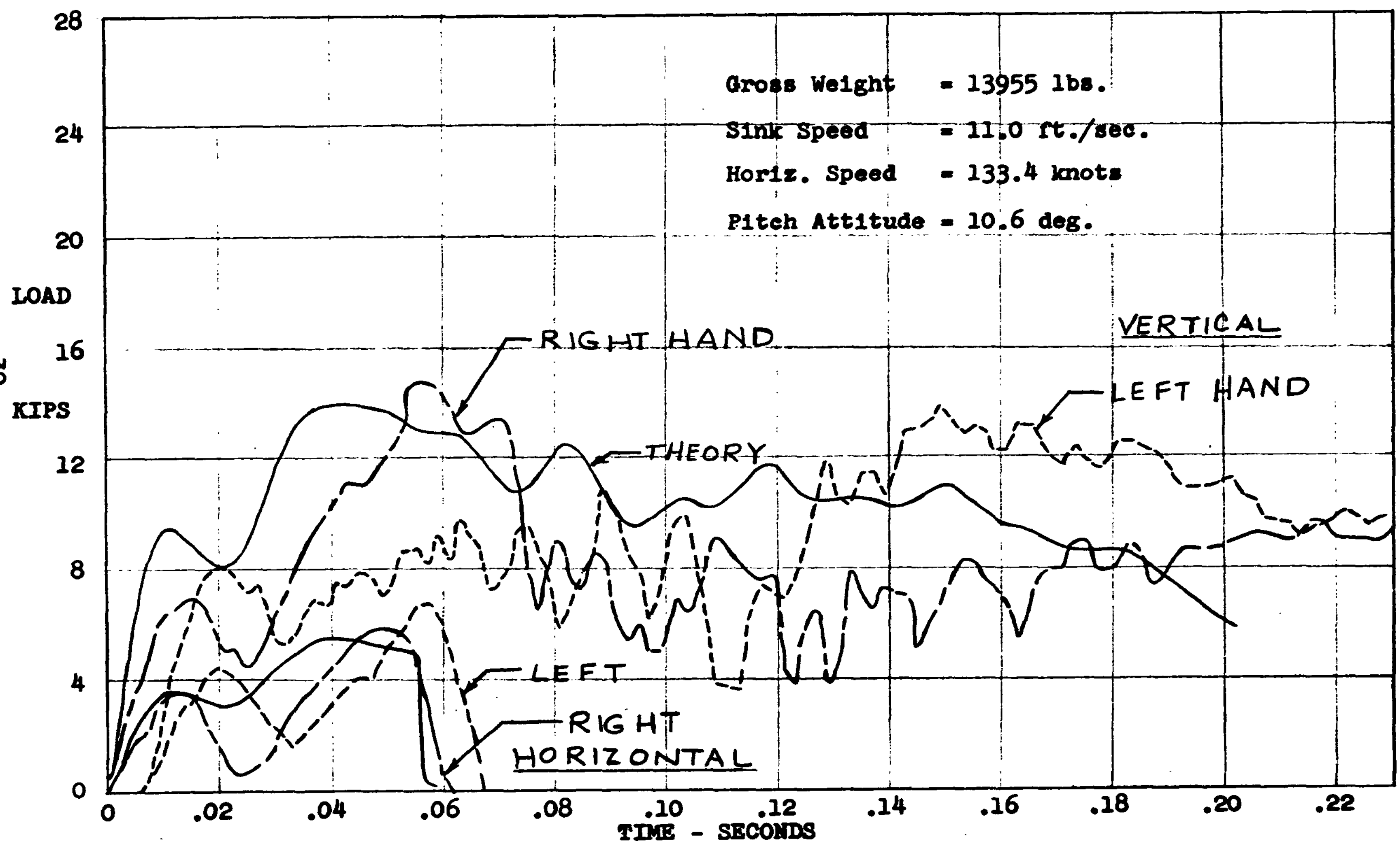


Figure 9. Vertical and Horizontal Ground Load Comparison, Landing 146 and Theory.

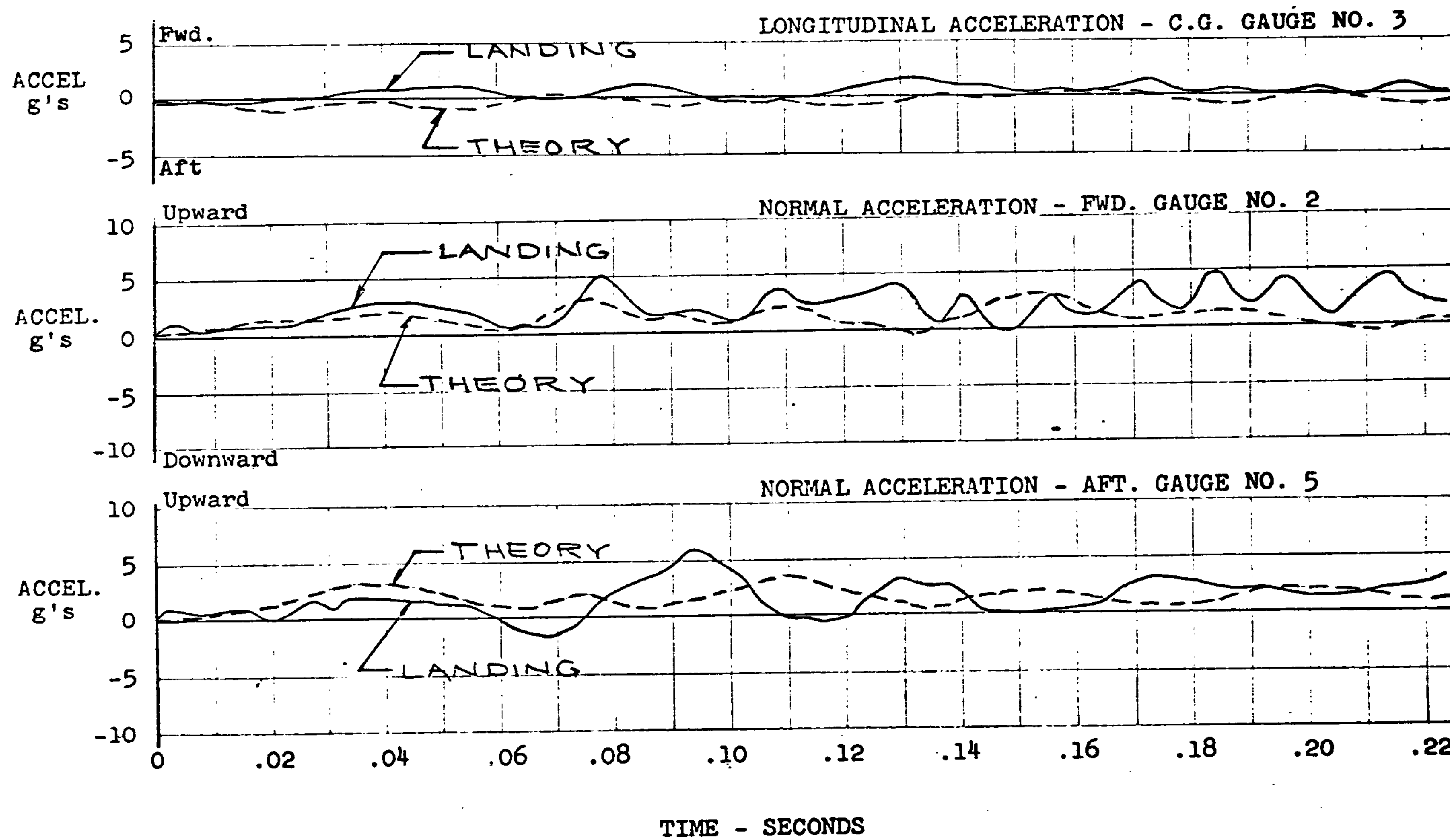


Figure 10a. Left External Fuel Tank Acceleration, Landing 146 and Theory.

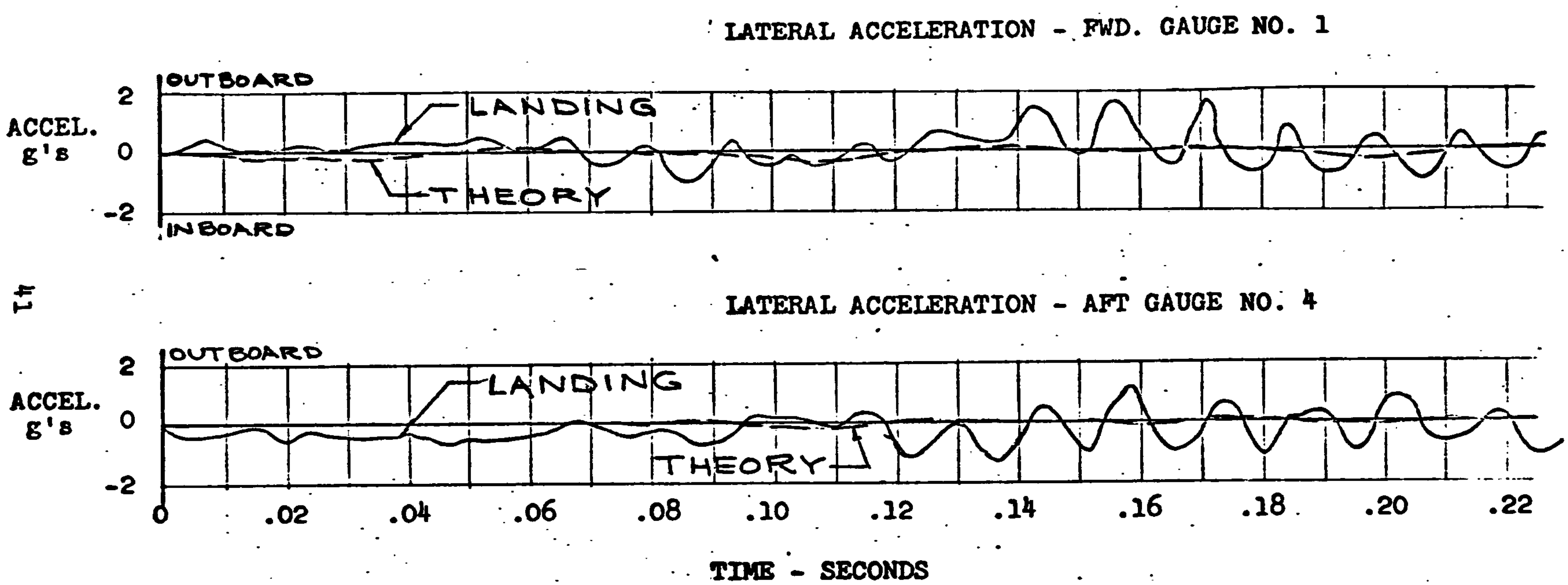


Figure 10b. Left External Fuel Tank Acceleration Landing 146 and Theory.

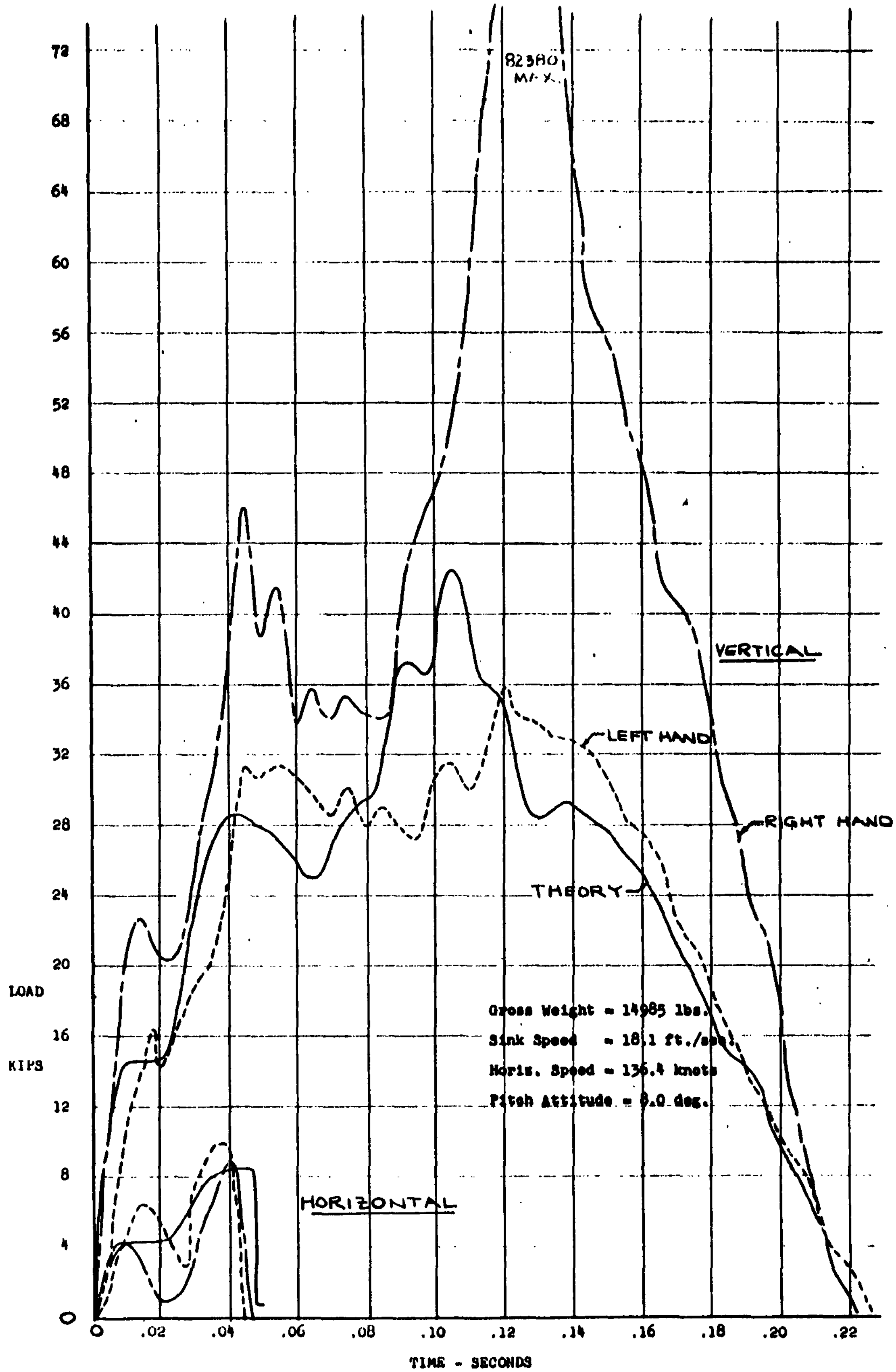


Figure 11. Vertical and Horizontal Ground Load Comparison, Landing 152 and Theory.

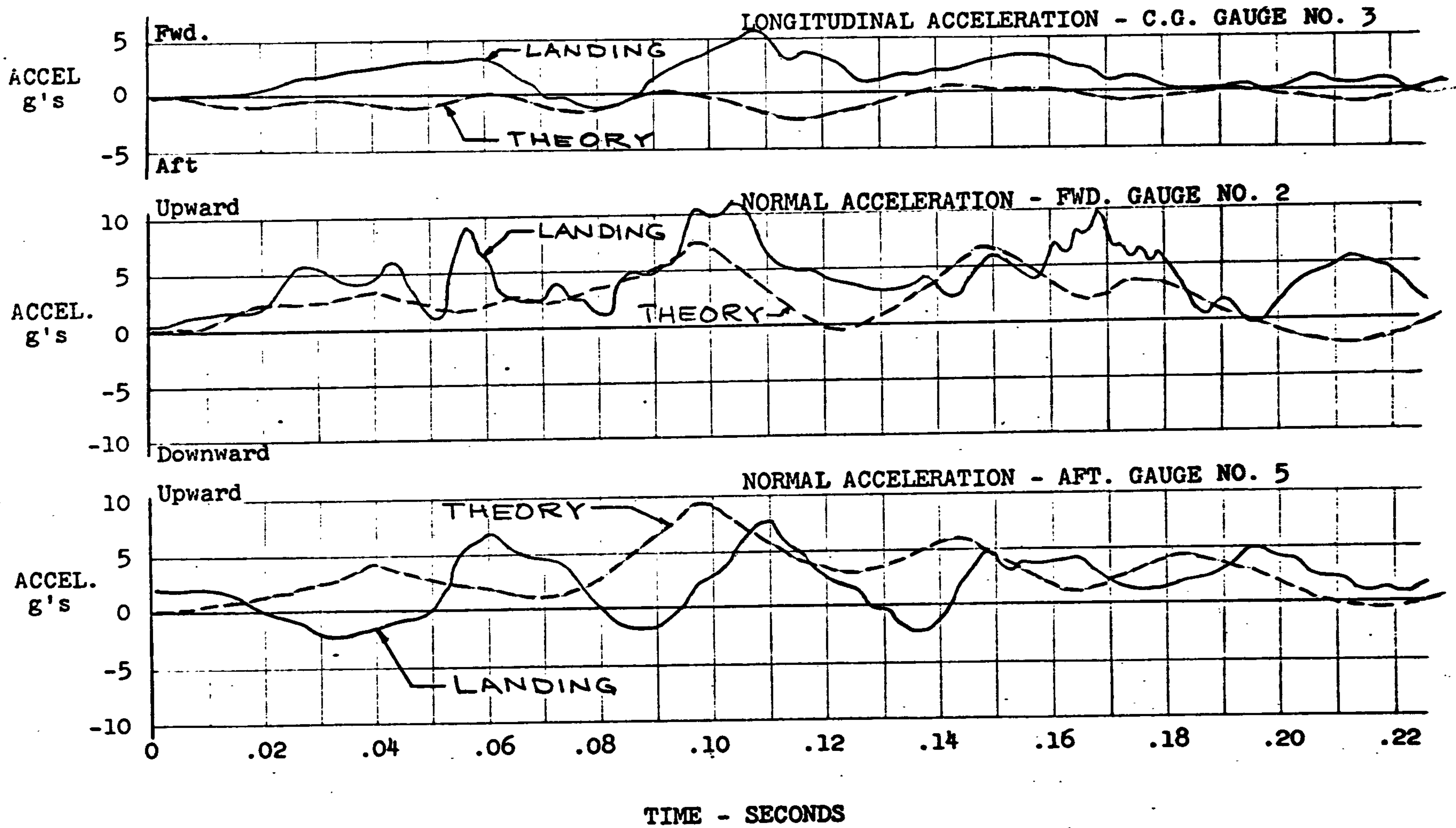


Figure 12a. Left External Fuel Tank Acceleration, Landing 152 and Theory.

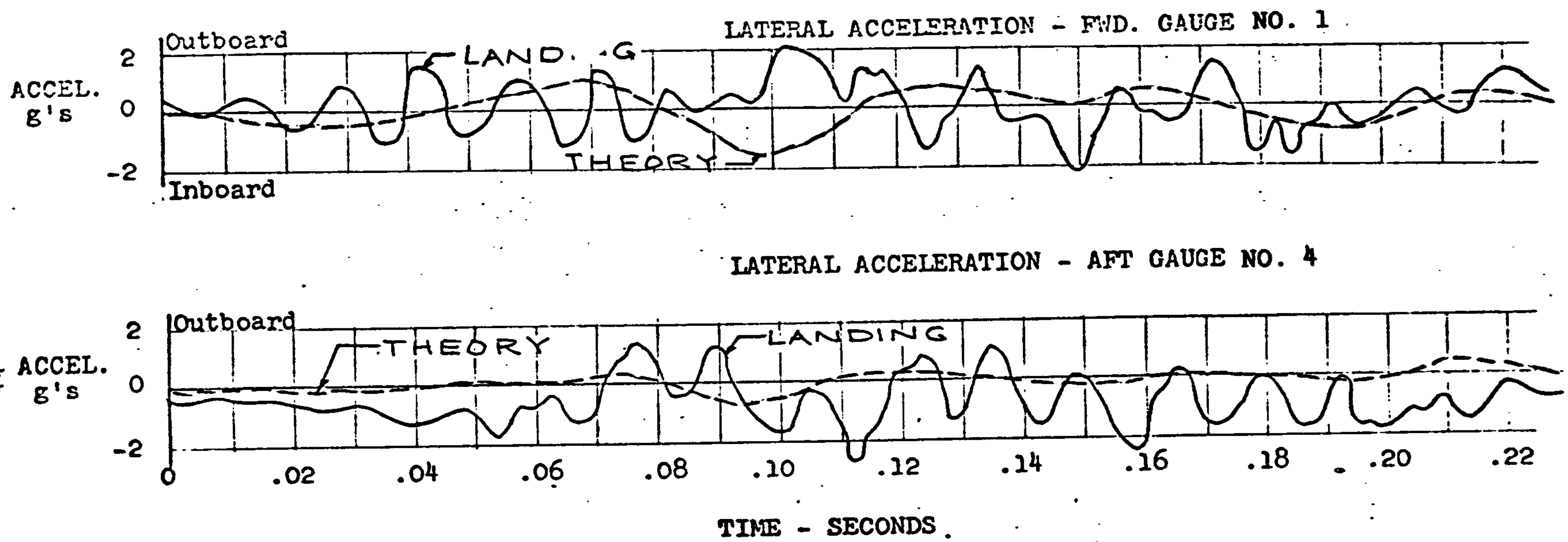


Figure 12b. Left External Fuel Tank Acceleration, Landing 152 and Theory.

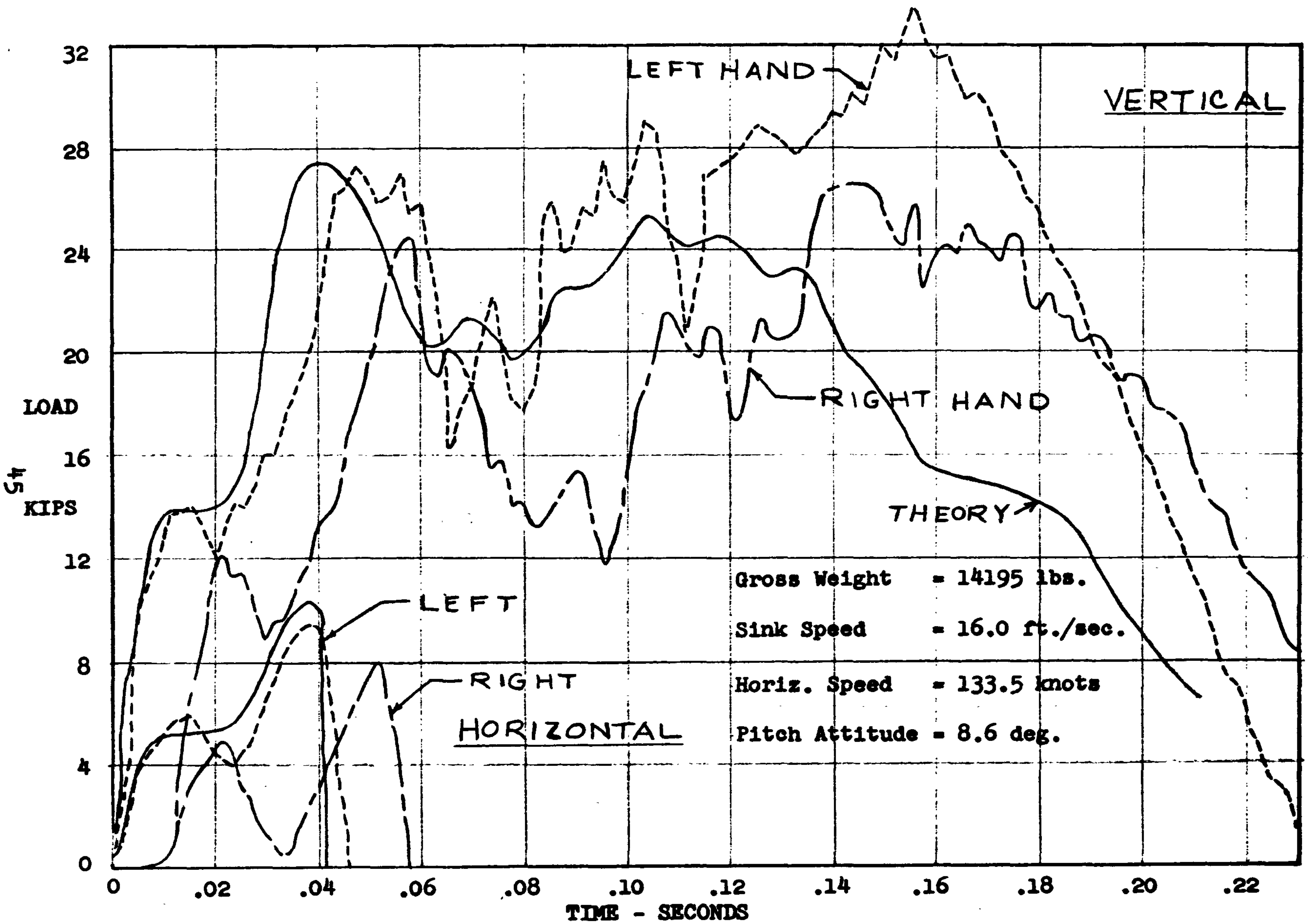


Figure 13. Vertical and Horizontal Ground Load Comparison, Landing 155 and Theory

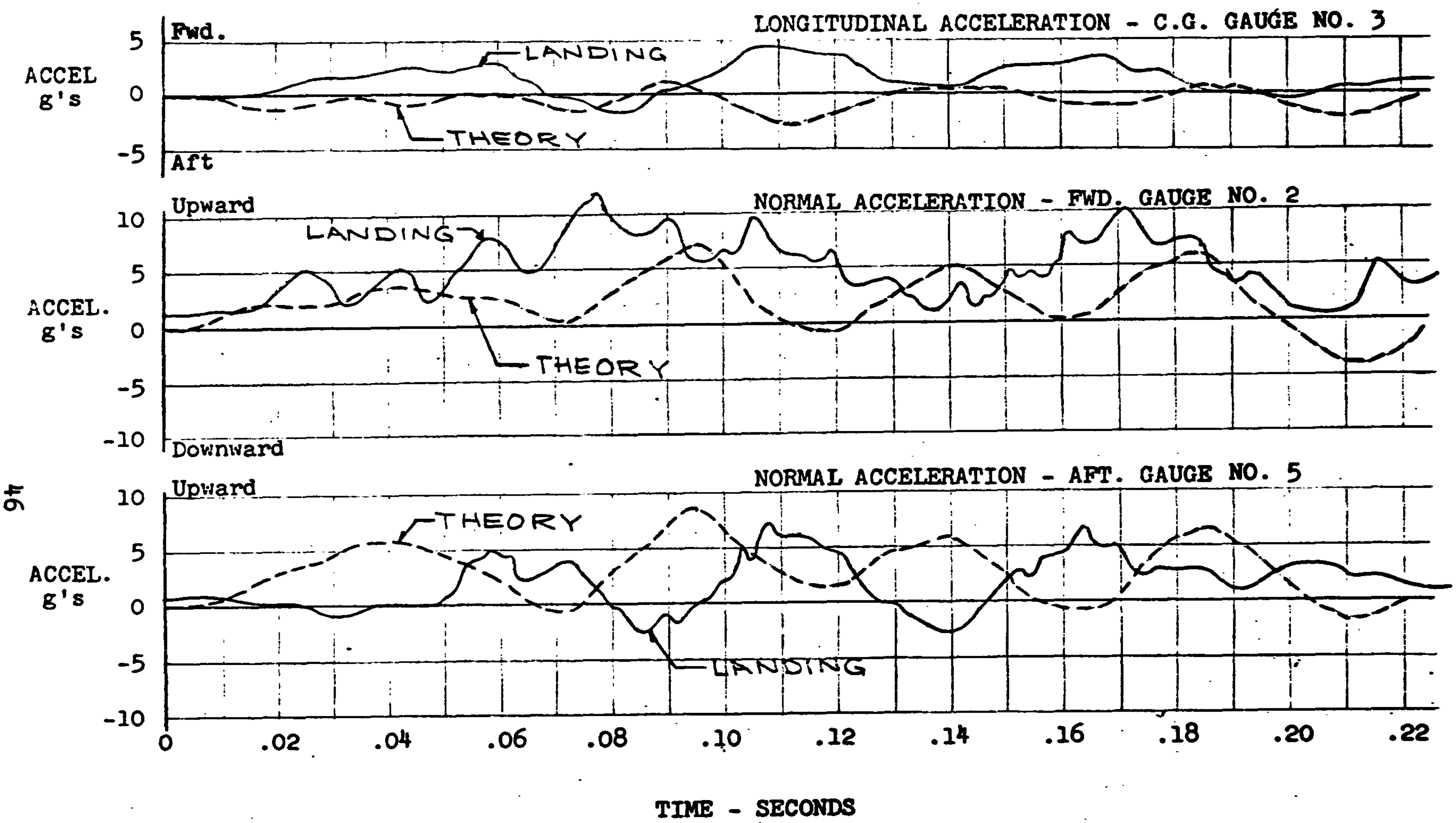


Figure 14a. Left External Fuel Tank Acceleration, Landing 155 and Theory.

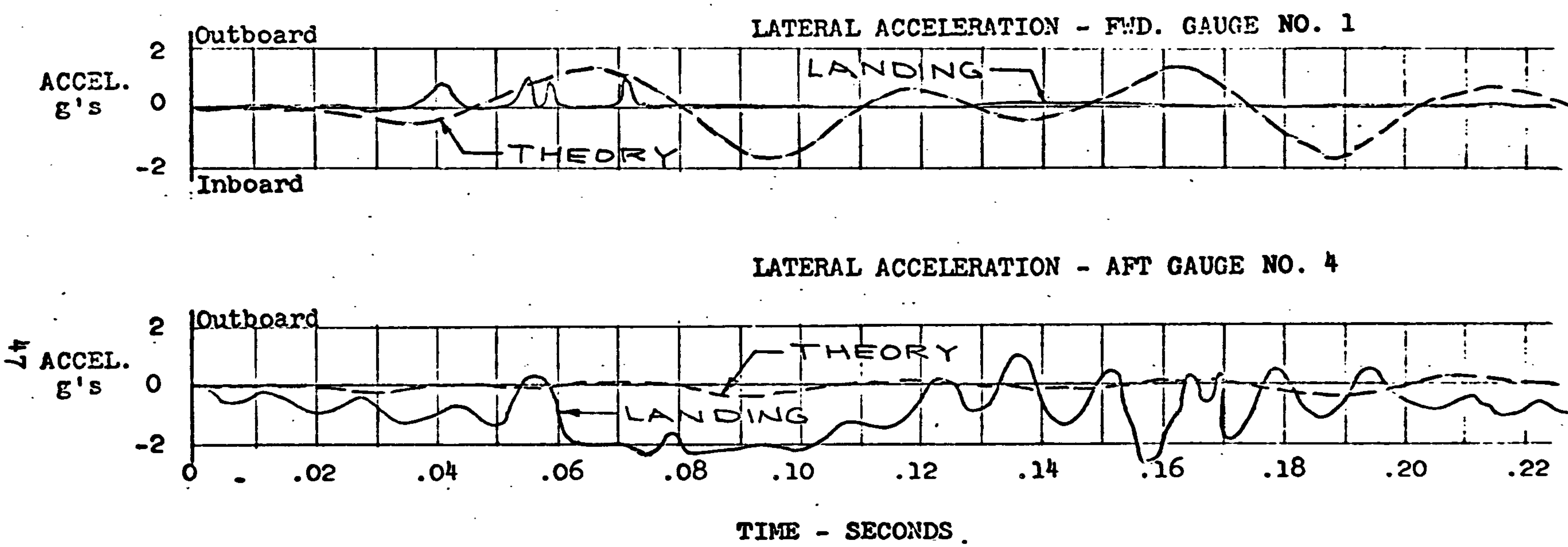


Figure 14b. Left External Fuel Tank Acceleration, Landing 155 and Theory.

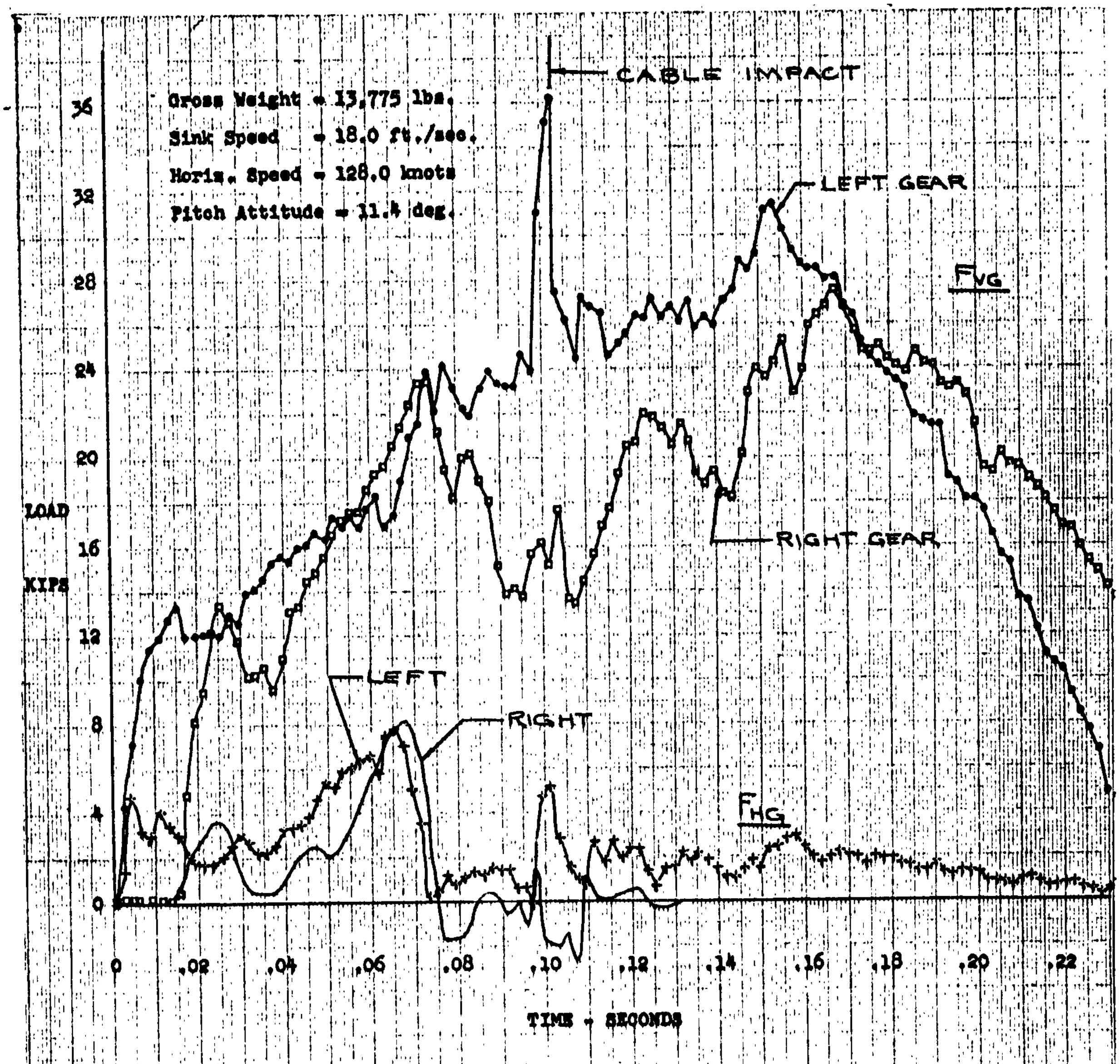


Figure 15. Vertical and Horizontal Ground Loads - Landing 179 - Arresting Cable Impact

GROUND LOADS

CABLE IMPACT LANDINGS

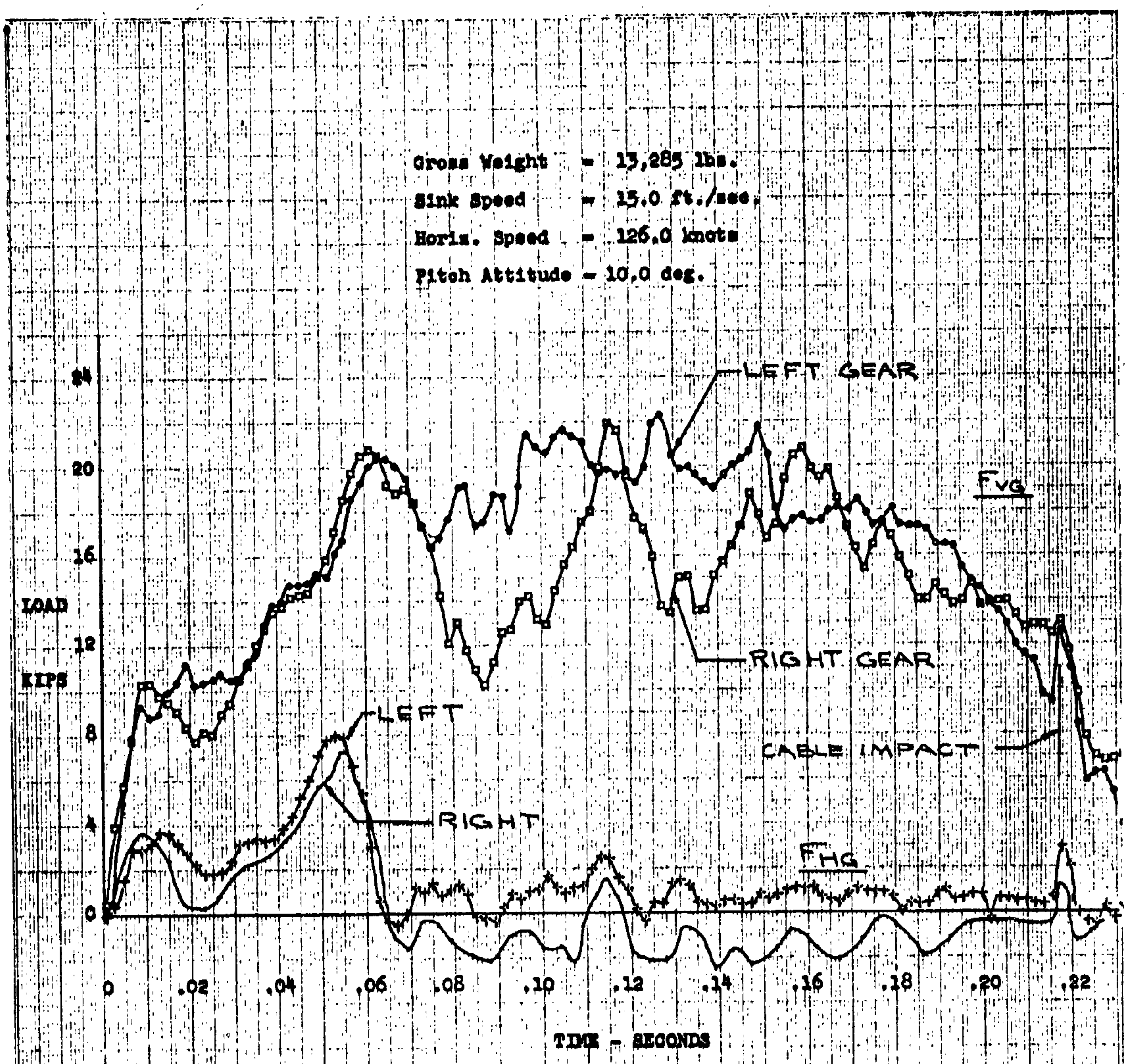


Figure 16. Vertical and Horizontal Ground Loads - Landing 188 - Arresting Cable Impact

GROUND LOADS

CABLE IMPACT LANDINGS

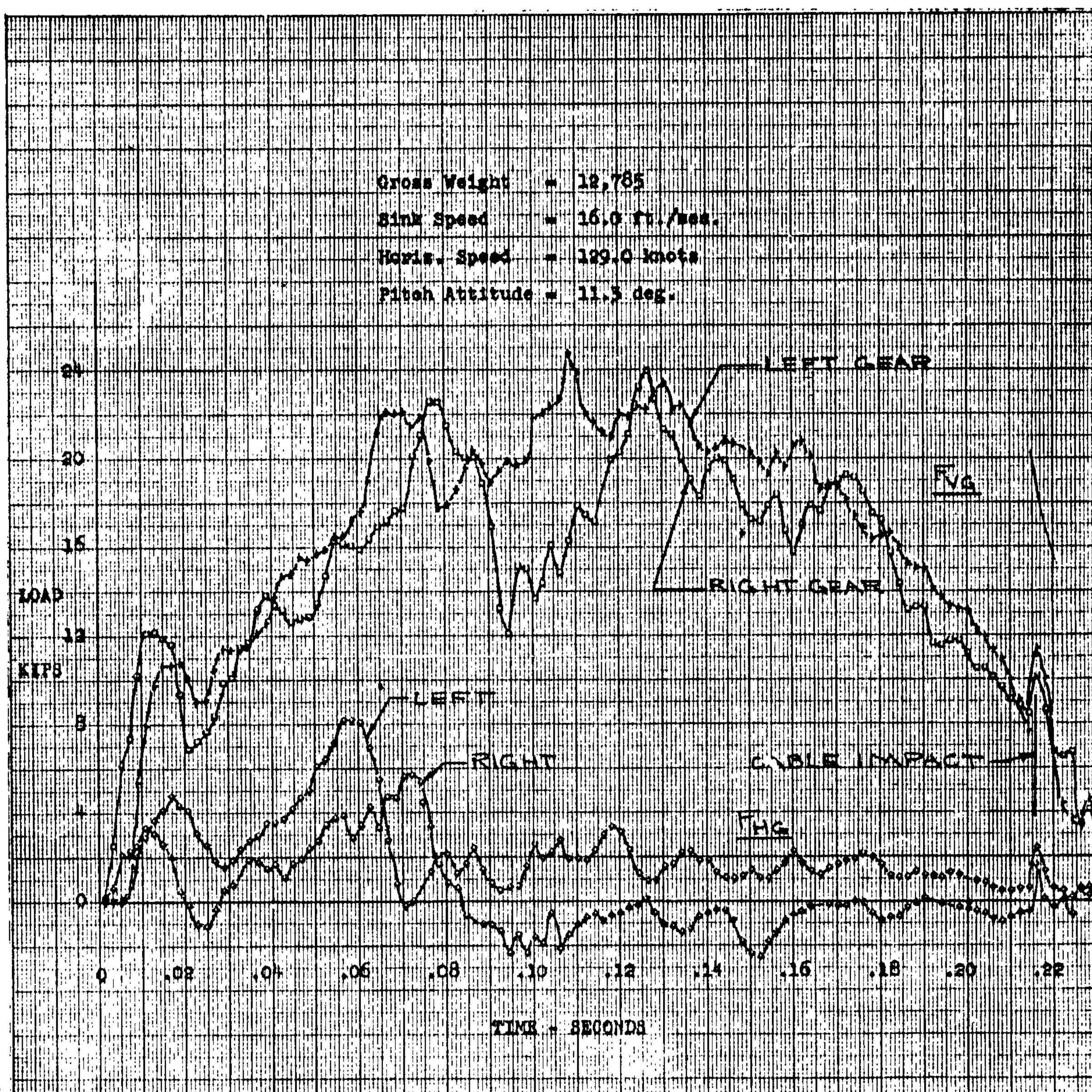


Figure 17. Vertical and Horizontal Ground Loads - Landing 190 - Arresting Cable Impact

GROUND LOADS

UNSYMMETRICAL LANDINGS

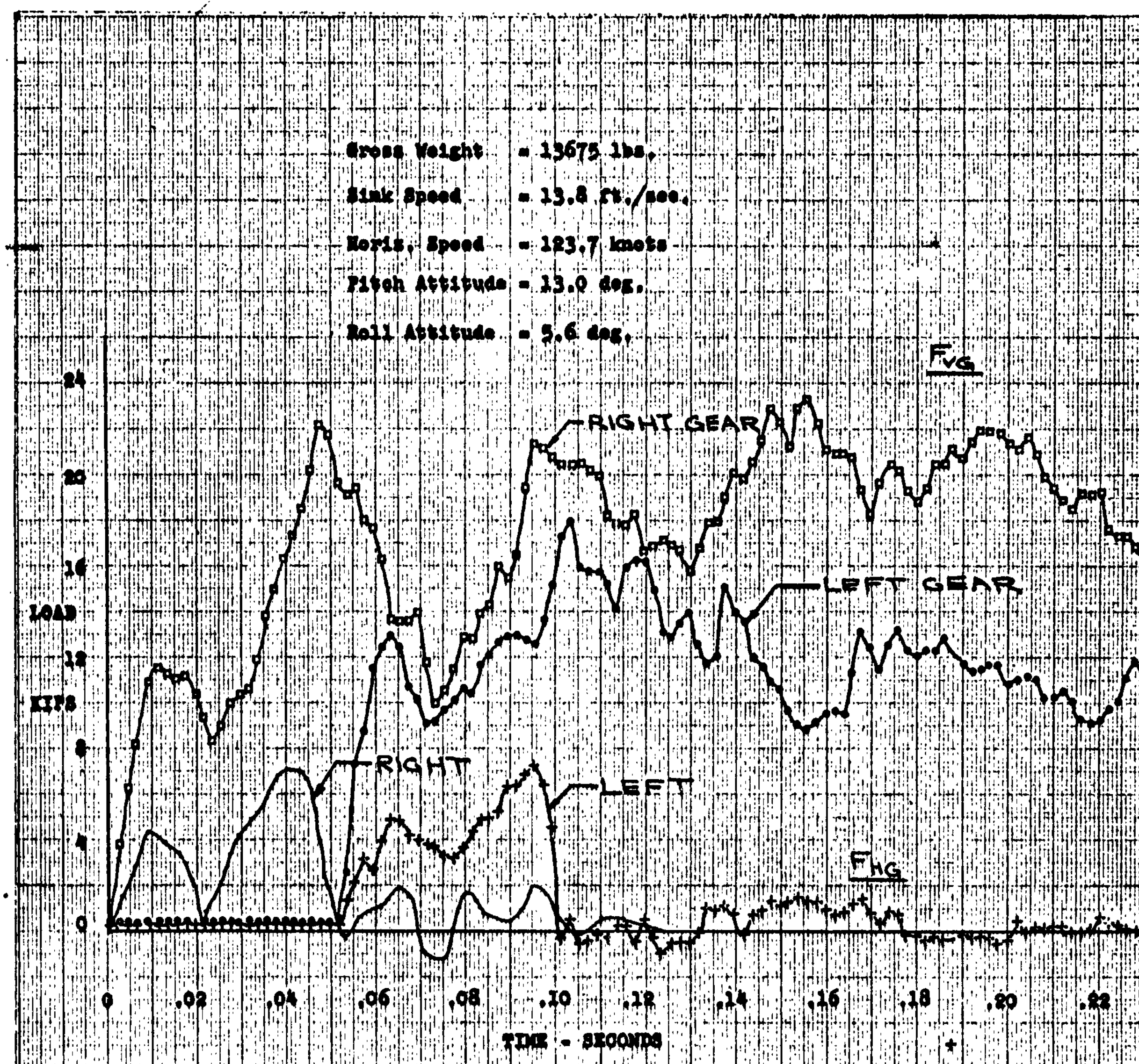


Figure 18. Vertical and Horizontal Ground Loads

Landing 167 - Unsymmetrical Touch-Down

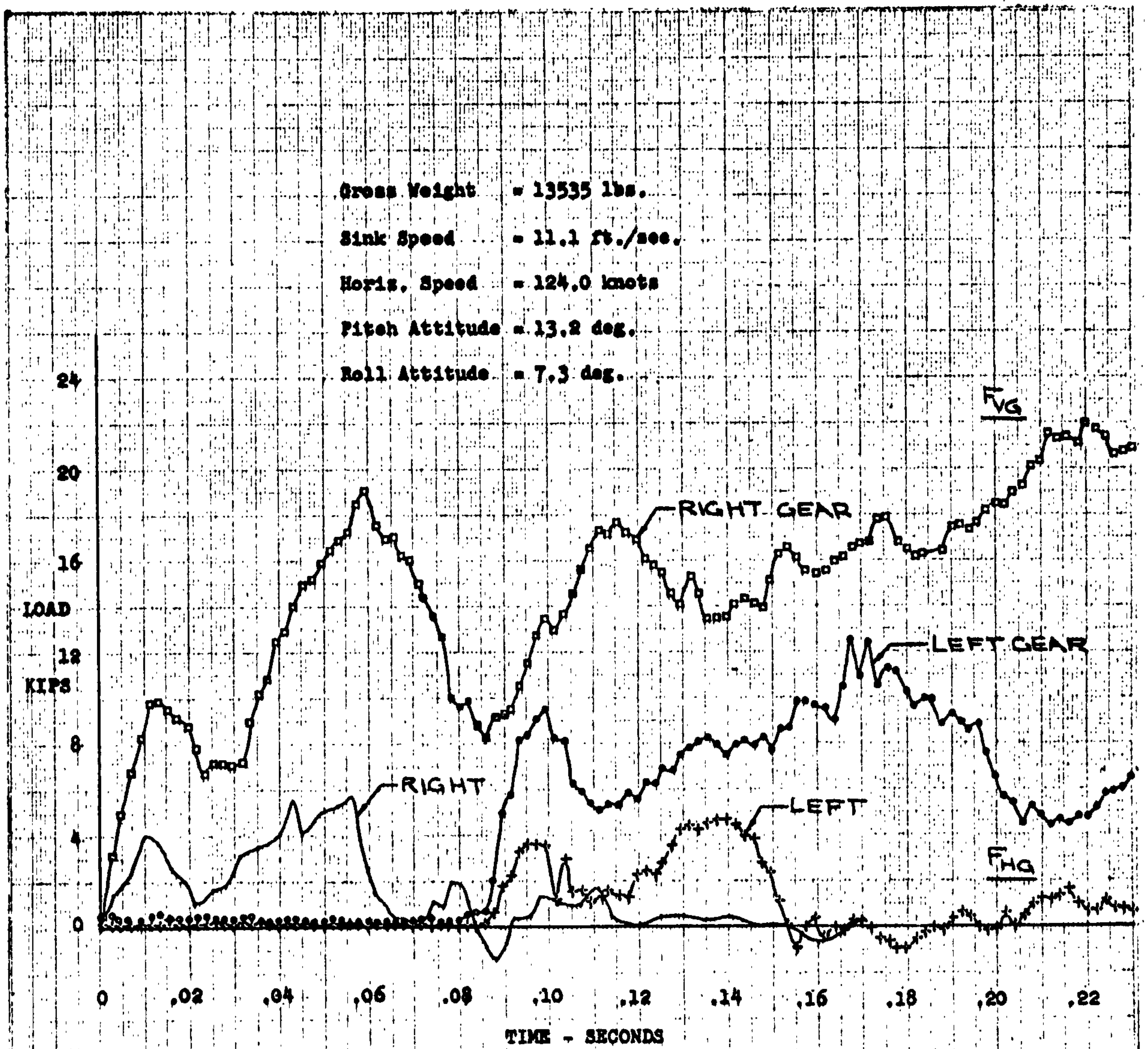


Figure 19. Vertical and Horizontal Ground Loads
Landing 168 - Unsymmetrical Touch-Down

GROUND LOADS

UNSYMMETRICAL LANDINGS

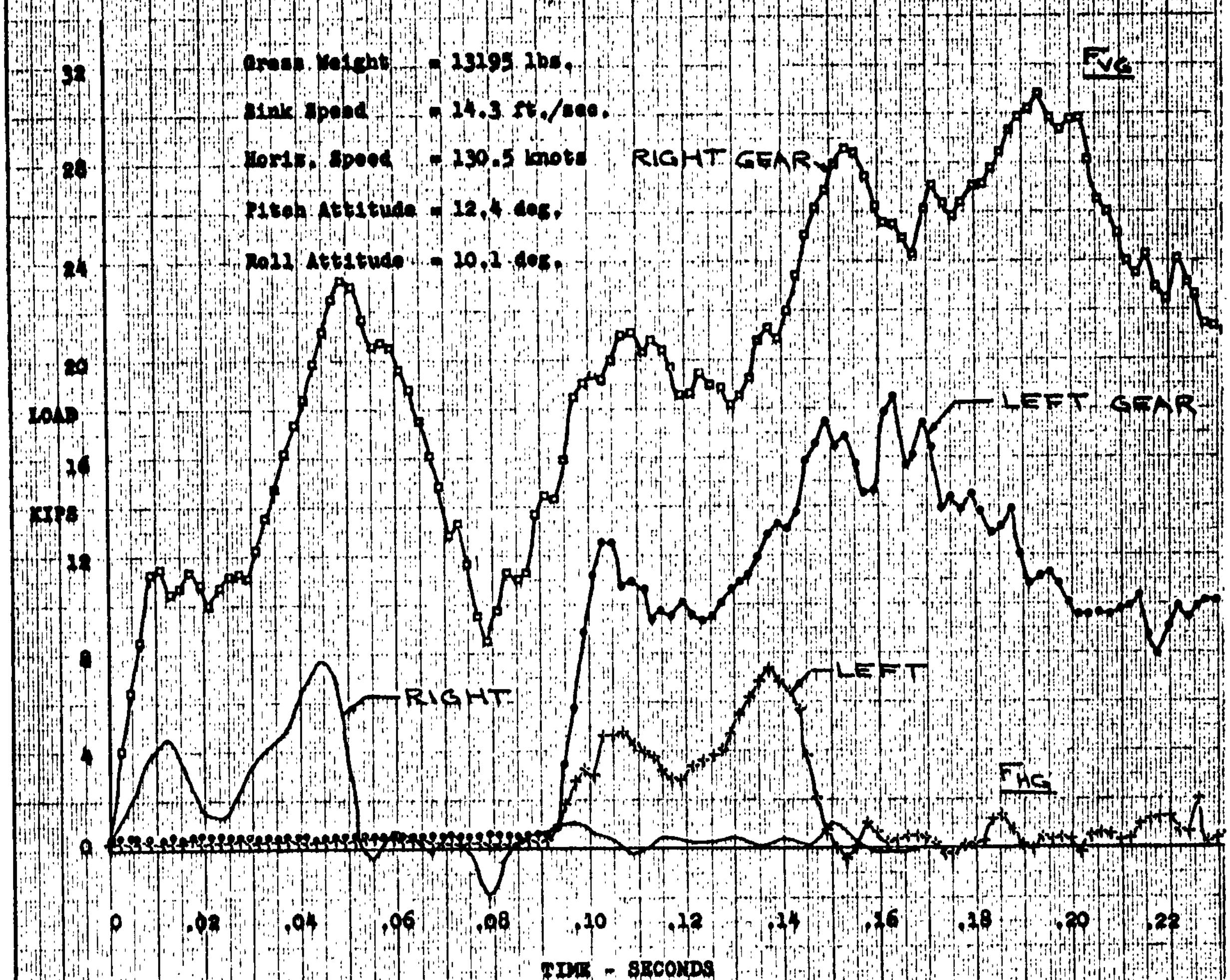


Figure 20. Vertical and Horizontal Ground Loads
Landing 170 - Unsymmetrical Touch-Down

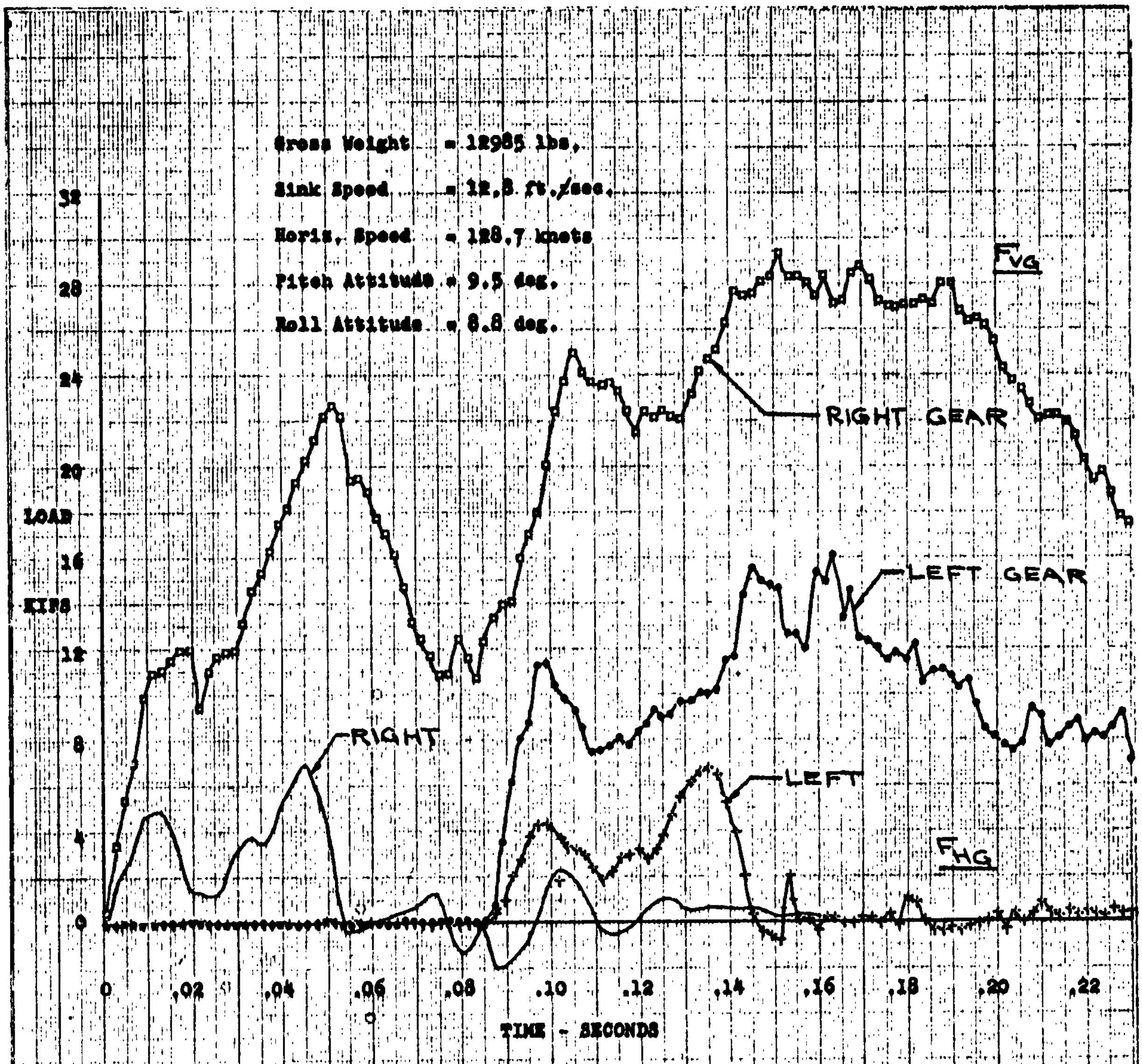


Figure 21. Vertical and Horizontal Ground Loads

Landing 171 - Unsymmetrical Touch-Down

Douglas Aircraft Co., Aircraft Div., Long Beach, Calif. Report No. LB-31074. Prepared for Bureau of Naval Weapons, Wash. D. C. LOADS EXPERIENCED BY THE A4D-2 AIRPLANE DURING LANDINGS WITH EXTERNAL STORES, DURING LANDINGS ON AN ARRESTING CABLE AND DURING UNSYMMETRICAL LANDINGS, Nov. 1962.
Final Report 64 p. inc illus., tables, refs.
Unclassified Report

Data are presented showing the loads developed during actual landings of the A4D-2 airplane with external stores mounted on the wing, during unsymmetrical landings and during landings in which the gear traversed an arresting cable. Results of a dynamic analysis are compared with the loads experienced during the external store landings only.

The correlation of analysis and theory was not considered satisfactory insofar as the external store accelerations were concerned. Recommendations for improving and extending the analytical work are presented.

The work described in this report represents the second phase of a comprehensive ground loads investigation, the first phase of which is reported in Douglas Aircraft Co. Report LB-31038 dated Oct. 1962.

1. Landing Loads
2. Loads, Aircraft
3. Cabl3 Impact
4. External Stores
I. Contract NOa(s) 59-6226c
II. Douglas Aircraft Co., Inc. Aircraft Div. Long Beach, Calif.
III. L. B. Mosby
IV. Aval fr Naval BuWeps

Douglas Aircraft Co., Aircraft Div., Long Beach, Calif. Report No. LB-31074. Prepared for Bureau of Naval Weapons, Wash. D. C. LOADS EXPERIENCED BY THE A4D-2 AIRPLANE DURING LANDINGS WITH EXTERNAL STORES, DURING LANDINGS ON AN ARRESTING CABLE AND DURING UNSYMMETRICAL LANDINGS, Nov. 1962.
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